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Transfer Penalties in Urban Mode Choice Modeling

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Travel Model Improvement Program

The Department of Transportation, in cooperation with the Environmental Protection Agency, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

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2. To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and

3. To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decisionmakers in state governments, local governments, transit agencies, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

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ABSTRACT

This is a report on recent research done on the subject of transfer penalties in urban mode choice decision-making. The research was undertaken to determine whether such penalties, thought by many observers to exist, are quantifiable. If so, then the Federal Transit Administration has a firmer basis on which to gauge the merits of travel model sets and the forecasts of transit ridership that they produce.

Using Boston area household travel survey data and hand-coded transit impedance data, mode choice models containing transfer-related variables were estimated by the Central Transportation Planning Staff. Transfer penalties for work trips were, in fact, found and quantified. In models based on an extremely carefully constructed data base, a transfer dummy variable representing whether a transfer is required to complete a trip, emerged as a modestly significant variable. It was found to be equivalent to 12 to 15 minutes of transit in-vehicle time, depending on the particular model specification. Other interesting and useful information emerged from this research as well. It was found that hand-coding transit impedances and establishing fairly liberal definitions of whether transit is an available mode had a significant impact on model estimation and resulted in more accurate parameter coefficients.

1.0 INTRODUCTION

This report describes a recent project done by the Central Transportation Planning Staff (CTPS)[1] for the Federal Transit Administration (FTA) on the subject of transfer penalties in urban mode choice decision making. The project was undertaken in response to FTA observations that the existence of transfer penalties makes intuitive sense, but that little hard evidence about them has been generated. The question is of more than academic interest, since many transit projects being evaluated in the U.S. consist of light rail services to which feeder buses would connect. In many cases, these projects are compared to baseline bus services or alternative TSM bus services that allow many travelers to make their trips without having to transfer. The feeder bus/rail alternatives, on the other hand, would require considerable transferring. It is, therefore, critically important that the impact on mode choice of having to transfer be accounted for to the fullest possible extent.

This project yielded some interesting and important information regarding transfer penalties. Using an eastern Massachusetts household travel survey data set and other information, a transfer penalty worth about 12 to 15 minutes of in-vehicle time was found for work trips. This penalty was found to exist over and above the disutility associated with each minute spent in transferring. Other interesting findings about data used in model estimation and model specifications emerged as well, and are reported on in this document.

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[1] The Central Transportation Planning Staff is the technical support staff for the Boston MPO. That MPO is composed of the Executive Office of Transportation, the Massachusetts Highway Department (MHD), the Massachusetts Bay Transportation Authority (MBTA), the MBTA Advisory Board, the Massachusetts Port Authority (MassPort), and the Metropolitan Area Planning Council (MAPC).

This report synthesizes information from two previous papers[2] and also contains additional information about the data used and experiments conducted during the course of the project. The report is divided into eight major sections. The next section provides background information about the project and its objectives. The approach is described in the third section, and the data set and experiments relating to the data are described in the fourth section. Section Five presents results and Section Six discusses outstanding issues. Summary comments about the results of the project are contained in Section Seven. The last section presents our recommendations.

2.0 BACKGROUND

2.1 Impetus for Project

Based on their review of ridership forecasts done for various Alternatives Analyses/ Environmental Impact Statements conducted around the country, FTA became concerned that the ridership-dampening effect of transferring might not have been adequately accounted for in the travel forecasting. In several cases, "build" alternatives were specified in which a new radial rail line would serve a corridor, and existing bus lines would be reoriented to feed that rail line. The resulting forced transfer for many riders might be expected to lessen the ridership potential of these alternatives, but some of the forecasts FTA reviewed appeared not to reflect this expectation.

There was not much quantitative evidence about the impact of transferring on urban mode choice, so FTA staff was unable to propose specific adjustments to some of the ridership forecasting methods they reviewed.[3] Common sense and available evidence did, however,

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[2] Quackenbush and Gallagher, *Data Issues in Mode Choice Model Estimation*, May 1993. Presented at the Fourth TRB Transportation Planning Applications Conference. And Quackenbush, McClennen, and Gallagher, *Transfer Penalties in Mode Choice Decisions*, April 1995. Presented at the Fifth TRB Transportation Planning Applications Conference. Both papers are available in the published compendium of papers from each conference.

[3] The authors are aware of only four other studies where surveys were used to investigate transfer penalties, and three of these were with respect to path choice rather than mode choice. Kenneth Train, (*A Validation Test of a Disaggregate Mode Choice Model*, Transportation Research, Vol. 12, No. 3, pp. 167-174) estimated a mode choice model for the Bay area which included both transfer wait time and number of transfers as variables. Only transfer wait was significant at the 90 % level, with coefficients in the range of -0.0438 to -0.0538, and valued as twice as onerous as transit in-vehicle time and 165 to 190% of the average wage rate (another variable). Anthony Fu-Wha Han, (*Assessment of Transfer Penalty to Bus Riders in Taipei: A Disaggregate Demand Modeling Approach*, TRR 1139, pp. 8-14) used a survey of bus riders to estimate a logit model of bus path choice and found a penalty worth 10 minutes of wait or 30 minutes of in-vehicle time. John Douglas Hunt, (*A Logit Model of Public Transport Route Choice*, ITE Journal, Dec., 1990, pp. 26-30) used a survey of Edmonton transit users and also found a transfer penalty at the path level which was worth almost 18 minutes of in-vehicle time. Alan J. Horowitz and Dennis J. Zlosel, (*Transfer Penalties: Another Look at Transit Riders' Reluctance to Transfer*, Transportation 10, 1981, pp. 279-282) did not estimate a model, but found surveyed bus passengers preferred not to transfer, regardless of the transfer time involved. Finally, a Seattle survey of work mode choice models, referenced in *Short-Term Travel Model Improvements*, US DOT, DOT-T-95-05, October 1994, found coefficients for transit transfer times between -0.033 and -0.114 for work mode choice models developed in 5 cities between 1960 and 1984. No additional information was provided about these models.

suggest that there is a transfer penalty associated with urban mode choice decision making. Since decisions were being made involving millions of dollars for new light rail services, FTA decided to investigate the matter to see if specific information could be developed that would allow travel models to better reflect transfer penalties.

The Central Transportation Planning Staff had just embarked on a major travel model improvement effort which included conducting a household travel survey and estimating new mode choice models. At FTA's request, CTPS agreed to use that survey information and its expertise in model development to analyze the mode choice consequences of transfers in the Boston region.[4]

2.2 Project Objectives

The primary, and sole original, objective of this work was to determine whether the existence of transfers in the Boston area transit system reduces the likelihood of choosing the transit mode, and if so, to what degree. It was not necessarily the intent of the research to yield specific model parameters that could be transferred to other cities, but it was assumed that, if a transfer penalty could be found for one city, there would be a very good chance of finding it in other cities. The FTA was hopeful that the information developed in this project would lead to additional work by others, and that, where appropriate, transfer penalties would start to appear in other model sets.

As research commenced, a supporting, secondary project objective materialized. This derived from our approach to creating a data set for model estimation. That approach, as will be described more fully later on, was a very cautious one. We were determined to construct as accurate a data set as possible -- one free of errors and biases that might throw into question our conclusions about transfer penalties. To that end, we spent a considerable amount of time preparing transit paths and impedances, deciding how to specify whether transit was an available mode for the travelers in the data set, and testing alternative definitions of key variables. Our secondary objective, then, was to determine whether all the extra care spent on these tasks had been worthwhile, and whether others should also spend time on them in their own modeling efforts.

2.3 Transit in the Boston Area

The Boston area's transit system is extensive and complex. In addition to a large network of local and express buses, the latter provided both by the Massachusetts Bay Transportation Authority (MBTA) and private carriers, the system includes commuter rail, heavy rail, light rail and commuter boat lines. Figure 1 provides some idea of the geographic extent of transit coverage in eastern Massachusetts (due to the scale, only commuter rail lines are shown).

Transfers within and among transit submodes are common. Overall, 39 percent of linked transit trips involve one transfer and seven percent involve two or more. Those between local buses and

[4] Until now, CTPS was among those who did not explicitly penalize transfers in its mode choice models. The only transfer penalty used was in transit path building.

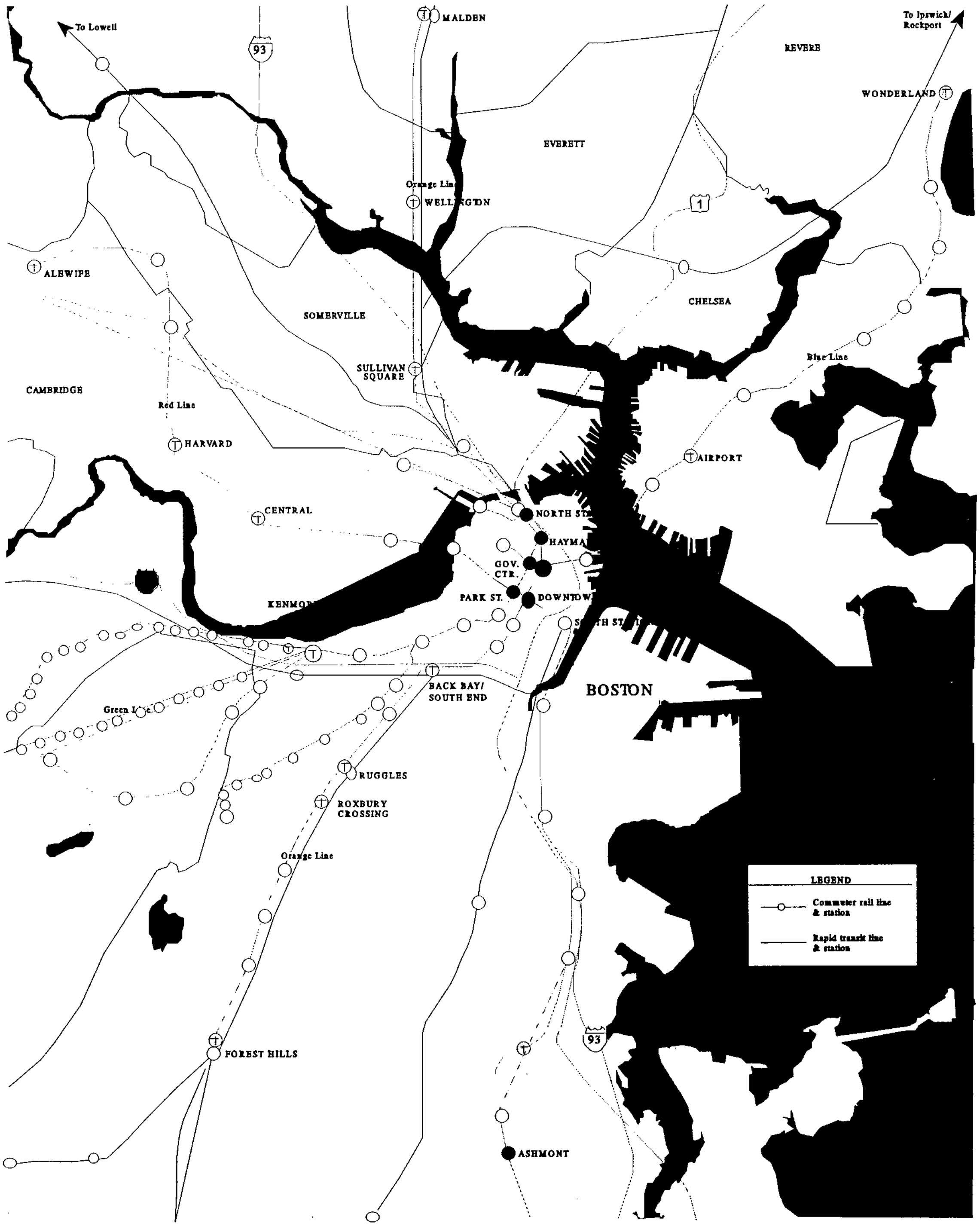
heavy rail are particularly common -- 23 percent of all linked trips -- because many travelers use feeder buses to access outer-area rail stations and then travel by rail to Boston's core area. Rail-to-rail transfers in the subway are also very common, as are those among local bus lines. There are no timed transfers in the system, and most transfers occur in sheltered locations. Figure 2 shows some of the heaviest transfer points in the region.

Transfers between rail lines in the subway are free, but all others require payment of the applicable full boarding fare. Monthly passes provide a discount and are heavily used, particularly for work trips. These passes are priced such that people who transfer receive a greater percentage discount than those who do not.

Figure 1
Rail Services in Eastern Massachusetts

K.D. CTPS 2/10/95

Figure 2
Major Transfer Points (Rail Transfers or at Least 10 Bus Routes)



3.0 APPROACH

This section describes the approach used in this project. It begins with an explanation of some key decisions that were made at the project's outset, and it goes on to describe, in general, how data were derived and analyzed to yield the findings that are presented in Section 5.0.

This section is designed to give the reader the essence of the approach, while Section 4.0 goes into considerable detail on the derivation and use of the data. Stated differently, this section provides an overview of what we did, while Section 4.0 describes why we did what we did, and how we measured impedances and other variables.

A couple of key decisions were made at the beginning of the project which strongly influenced its character. First, at FTA's suggestion, a Peer Review Panel was formed. This panel consisted of individuals knowledgeable about travel modeling and transit. It's purpose was to lend guidance to the research, and to help generalize findings beyond Boston. This panel proved to be an excellent resource for the project, and was a testament to the wisdom of convening such groups. The project benefited immeasurably from the suggestions and guidance offered by the panel.[5]

With the advice and concurrence of the panel, a key decision relating to data quality was made early. We wanted to ensure that findings regarding transfer penalties be untainted by data or specification problems. Accordingly, as described more fully later, we decided to "hand-code" transit paths and associated impedances in constructing our model estimation data set. It was thought that doing so would result in much more accurate transit paths and time impedances for both transit and auto choosers, hence more accurate and reliable model estimation results. We also took considerable care in measuring and representing cost and household-related variables.

The decision to expend extra resources on data quality meant that the research had to be constrained in other respects. Accordingly, it was limited to work trips with the hope that, if any promising findings emerged, we or someone else would subsequently conduct similar research on non-work trips. In addition, the expense of hand-coding transit paths meant that we could only provide one such path per traveler in the data set, so we could not model path choice and mode choice together.

3.1 Create Estimation Data Set

With data quality a prime consideration, an estimation data set was constructed for subsequent input to mode choice model estimation. This data set relied chiefly on a household travel survey, hand-coded transit impedances and network-derived auto mode impedances. This section describes key features of the data set and how it was constructed.

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[5] The panel was made up of Daniel Brand, Charles River Associates; Bob Harvey, Regional Transit Authority, Seattle; Keith Lawton, Portland Metro; and Don Pickrell, Volpe National Transportation Systems Center. Ron Jensen-Fisher, the FTA client for this project, also participated on the panel.

3.1.1 Selection and Weighting of Trip Records From Household Travel Survey

The trip records in the estimation data set were chosen non-randomly from a 1991 eastern Massachusetts household travel survey. The non-randomness resulted from our selecting nearly all work-trip records for which transit was the chosen mode and a transit path could be determined. Shared-ride (SR) chooser records were over-sampled as well, and we chose as many single-occupant vehicle (SOV) chooser records as we could afford to provide with a hand-coded transit trip. We selected records in this manner to insure that the transit and shared-ride modes had an adequate sample size. Trip records were subsequently weighted by mode chosen and certain household characteristics in order to create, in effect, a random sample. There were 1,462 unweighted records in the final data set, distributed by chosen mode as follows: single-occupant vehicle 591, shared-ride 271 and transit 600[6]. After weights were applied, the distribution of trips was: SOV 1,189, SR 129 and transit 143.

3.1.2 Derivation of Modal Costs and Times

3.1.2.1 Transit Paths

Transit paths were manually found, and times were "skimmed" from these paths manually (This process is referred to in this report as "hand-coding"). Paths of transit choosers were largely reconstructed from the household travel surveys. In some cases, respondents were called to clarify the characteristics of their trips. In other cases, where certain characteristics of a traveler's chosen transit trip were ambiguous, we developed a set of decision rules, based on the unambiguously chosen transit trips and on some access coding experiments, and imputed characteristics accordingly.

Transit trip paths for SOV and SR choosers were established using decision rules based on chosen transit trips and on the access coding experiments. Many "poor" alternative transit trips were coded. These were paths requiring transfers, with long access/egress legs or long waits. For theoretical reasons, and based on empirical results, unlikely but possible alternatives were believed to be necessary to understanding the true choice decision. (See Section 4.0 for more discussion of this.)

In cases where the specific path of a chosen transit trip was ambiguous, and for all transit paths for SOV and SR choosers, we chose the hand-coded path based on two general rules. First, walks of less than one mile were favored over drive access to transit, which everyone was assumed to have. (We did not check to see if the household owned a vehicle, but assumed everyone could find a shared-ride to access transit, if necessary.) Second, when in doubt, the selected transit path was the one that minimized total travel time.

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[6] For the final estimation file used in transfer penalty estimation, trips where household income was missing, and when transit OVTT/IVTT exceeded 10, were excluded. This left 1337 unweighted trips, 542 SOV, 259 SR, and 536 Transit.

Hand-coded transit paths were always highly specific to the time of day of the trip; hence, headways, bus running times and drive access times were for the exact time of travel. Trip ends were located at the U.S. Census block level. Access/egress walk legs were specified along streets connecting block centers and either the named or most likely transit stop. Drive access legs were found with our highway network assignment for ease, and because we did not think manual methods could improve upon the network-based results in this case.

3.1.2.2 Transit Travel Times

Once transit paths were established, maps and scheduling information from transit operators were used to measure the in-vehicle time portion of each one. Access/egress walk time was measured from maps assuming an average walk speed of three miles-per-hour. Walking time at stations between streets and platforms was field measured, as was transfer walking time among platforms within stations. Initial and transfer waiting time was assumed to be one-half the headway and no caps were imposed on these waits.[7] The lack of caps is counter to typical practice, but was consistent with what came to be our general approach of being quite "liberal" in our definition of what is considered to be an available transit alternative (as will be discussed in Section 4.0).

Other transit path and skimming conventions that emerged from the research might also be considered by many to be quite liberal, but they were based on reported behavior in the household travel survey or empirical tests. These conventions were as follows:

- Maximum walk distance is 2.0 miles at the home end and 2.0 miles at the work end of a trip.
- Maximum drive distance -- no cap.
- Maximum ratio of out-of-vehicle to in-vehicle time for a trip is 10.0 in order to place <u>some</u> limit on the definition of a reasonable transit trip that a traveler would consider.

3.1.2.3 SOV and SR Paths

The CTPS regional model was the source of all SOV paths and impedances used in this research, and provided the transit skims for comparison to the hand-coded results. Its 348 individual transit lines represent all of the MBTA services and most of the other services mentioned above. The network is tied to a zone system consisting of 787 internal and 102 external zones. The CTPS regional highway network used in this research includes over 38,000 one-way links and 14,000 nodes. It was the source for congested highway travel times and distance for the auto alternative throughout this research, and for the drive access portion of transit trips in the manually-coded data file. Assignments for the AM peak period, PM peak period, and three off-peak periods were used.

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[7] The Peer Panel had hoped that, in the project's spirit of developing highly accurate data for model estimation, we would have time to gather and analyze sufficient data to establish a potentially more accurate waiting time rule than simply one-half the headway. At fairly close headways, the less uniform a transit line's vehicle headways are, the greater the average waiting time. Unfortunately, we did not have the resources to address this.

Single Occupant Vehicle trips were considered an available mode for any licensed tripmaker whose household owned a vehicle. The Shared Ride mode was available to all. SOV and SR paths were identical between the same zone pair for any time period.

3.1.2.4 SOV and SR Travel Times

More precise highway mode travel times, comparable to the hand-coded transit times, were not developed for this project. We did not have the budget or information available to manually find preferred auto paths in a network filled with reasonable paths for most origin/destination pairs. In addition, we suspected that estimated parameters are not as sensitive to different auto in-vehicle times as they are to different transit out-of-vehicle times.

Highway paths and the times along them were derived from traffic assignments done with the region's travel model set. In-vehicle times for SOV's were, of course, equal to the times output from the travel model set. Those for the SR mode were established by regressing survey-reported SOV and SR times between the same zonal pairs. Regression results were then applied to modeled SOV in-vehicle times to yield SR in-vehicle times.

Out-of-vehicle times for the SOV mode are equal to the sum of the production and attraction terminal times used in the regional travel model set. Those for the SR mode were derived by applying the in-vehicle time regression results to SOV terminal times.

3.1.2.5 Travel Costs

Transit fares for all traveler records were specified as adult cash fare, and were specific to the traveler's transit path. Park/ride lot fees were specified as reported for transit choosers and, when applicable, inferred for SOV and SR choosers based on the particular park/ride lot included in their assumed non-chosen transit trip path.

Auto operating costs were calculated using 9.8 cents per mile (1991\$). Distances for those calculations for both auto access to transit and the SOV mode were derived from network assignments done by time of day. Shared-ride operating costs were found by dividing the corresponding zonal interchange SOV cost by the average SR occupancy of 2.4 riders per trip.

Parking cost for the SOV mode, if chosen by the survey respondent, was equal to reported parking cost, while that for transit choosers was set equal to the neighborhood/community average calculated from the household travel survey. Parking cost for the SR mode was found for choosers and non-choosers alike by dividing the corresponding SOV cost by average SR occupancy.

Costs in the final model estimations were divided by household income, as reported in the household travel survey. We were limited to specifying income as the mid-point of each quartile because actual incomes were not reported in that survey.

3.2 Model Specification and Parameter Estimation

With the data set in place, numerous model specifications were derived and input to ALOGIT for model estimation.[8] As shown in Section 5.0, each model specification contains at least one variable that describes transferring. In many specifications, transferring is represented by a dummy variable indicating whether or not at least one transfer is required to make the trip.

As mentioned above, the cost of constructing hand-coded transit paths limited us to providing just one path per traveler. We could not, therefore, model transit path choices in, for instance, a nested model structure. Thus, all of the models estimated focus just on mode choice and are of a multinomial structure.

3.3 Changes and Experiments with Data and Specifications

A key facet of our approach was that it involved a great deal of experimentation, and almost nothing remained static throughout the project. Both the data set and the way in which some variables were characterized in model specification evolved through the project. In fact, at some junctures, there was more focus on how to measure variable values or how to characterize a particular variable than there was on isolating transfer penalties. As stated elsewhere, much of this experimentation was done to ensure that neither data nor specification problems tainted transfer-related results.

However, much of it was also done as an end unto itself. We adopted a questioning attitude about how mode choice models are estimated, and essentially subjected everything to scrutiny. It seemed as if the further into the work we got, the more questions we had about how to do the job properly. Our Peer Panel concurred on the legitimacy of our inquiries and experiments, and suggested several areas of inquiry we had not thought of. The result of all this was that the project generated information and questions on a range of items related to transit network coding and mode choice model estimation beyond those having to do directly with transferring.

The next section includes detailed information on the most noteworthy of these experiments and their results.

4.0 DATA SET

This section provides information about the data set used in mode choice model estimation. It covers the contents of the data set, how the variable values were derived, experiments conducted in an attempt to structure the best data set possible, and issues that arose out of this work. This section expands on the previous one, and is quite detailed. One could, if desired, read the previous section, skip this one, and go right to the findings section without losing essential information on transfer penalties. However, this project generated some useful information and interesting questions about transit network coding, data measurement and variable

[8] ALOGIT is a discrete-choice model estimation package developed by the Hague Consulting Group.

characterization in mode choice model estimation, and this section should definitely be read by those interested in these subjects.

The section begins with a full description of the household travel survey that formed the basis of the model estimation. Following that are subsections covering the measurement and use of time, cost, transfer-related and socioeconomic variables.

4.1 Household Travel Survey

Model estimation is based on data from a 1991 eastern Massachusetts household travel survey, which provides an accurate representation of the region's household-based travel and demographic characteristics. Data were obtained from approximately 3906 households, with 38,116 trips made by household members over the age of five. Of these, 7058 were home-based work (HBW) trips.

There were two components of the survey: a household survey form and an out-of-home activity diary.

4.1.1 Household Survey Form

Each household member's age, sex, drivers license and employment status (unemployed, part-time, full-time, self-employed, work-at-home, student) was obtained. The number of workers was calculated during processing by combining the employment status of everyone in a household. In addition, aggregate household income and vehicle ownership/access was obtained. Household income was collected for six categories, and during data processing, these were reduced to four: $0-$19,999, $20,000-$39,999, $40,000-$59,999 and $60,000 and up. Household addresses were geo-coded to U.S. Census blocks or block groups.

4.1.2 Activity Diary

For a particular (pre-determined) 24-hour day, the characteristics of all out-of-home activities made by each household member over five years old were recorded in activity diaries. These activities were converted into trips during survey processing. A trip began at the end of one activity and ended at the beginning of the next one. During processing, these activity locations were geo-coded to U.S. Census blocks or block groups. The purpose, origin and destination, mode or sequence of modes, vehicle occupancy, and cost for each trip was collected in these diaries.

There were eleven purposes for each individual to choose from for each activity. This transfer penalty research, though, used only the home-based work trips. Both home-to-work and work-to-home trips were utilized.

The survey respondent recorded the mode or modes used to move from one activity to the next. There were eleven modes to choose from: walk, auto, MBTA bus, non-MBTA bus, rapid transit, commuter rail, the RIDE (a para-transit service for people with disabilities), school bus, bicycle, taxi and other. A single trip could consist of up to six different modes. For example, the trip for a person walking to an MBTA bus stop, taking the bus to a rapid transit station, taking rapid transit to the closest stop near his destination, and finally walking to his destination consisted of four modes (walk - bus - rapid transit - walk), all of which would have been recorded in sequence in the diary. If auto was reported as a mode, the respondent was asked how many other individuals were in the vehicle.

Survey respondents recorded the costs associated with each trip. If one of the modes was auto, the respondent was asked where she parked her car (private residence, street, parking lot), and if she paid for parking, how much she paid. In addition, if a portion of the trip was on any transit vehicle, the respondent was asked how much and by what means (cash fare, monthly pass, multi-ride commute book) she paid for the trip.

Finally, the respondent was asked how many minutes it took to get from one activity to the next. This time was subsequently compared to the difference between the ending time of one activity and the beginning time of the next in order to check for reasonableness. Along with cost information, it was also used to provide verification on the reported transit path.

No information was collected on available alternative modes and why they were not used.

4.2 Time Variables

Travel times were composed of in-vehicle (IVTT) and out-of-vehicle times (OVTT), with a variety of components and estimation methods used to determine the different SOV, SR, and transit times. Single-occupant-vehicle times came directly from the regional model. These SOV times were then transformed into SR times by adjusting them to account for extra pick up and drop off times inherent in that mode. Transit times included in-vehicle, walk, and wait times, determined using hand-coding methods, and drive access, from the regional network-based model. No information on these transit component times was collected in the eastern Massachusetts household travel survey. The details of estimating each time variable for each mode are presented below.

4.2.1 In-Vehicle Travel Times

In-vehicle times were estimated separately for each mode. Those for transit were based on the hand-coded travel path for each trip. One or more transit submodes, with on and off stops identified for each, make up each path. The transit in-vehicle time for each path was calculated from published schedules for MBTA bus, rapid transit, and commuter rail, and from other regional transit authorities in eastern Massachusetts. Numerous private express bus services also publish schedules, although they were not always available for the survey time period. Commuter boat schedules were also used, although very few trips were made using this submode. Various techniques were used to estimate IVTT for rapid transit, commuter rail, and bus services.[9]

Transit IVTT is the sum of all IVTTs for all the submodes in a transit path. In-vehicle times were also available as initial IVTT and transfer IVTT, where the latter was the time on the second and all subsequent legs of the trip. Time in an auto to access transit was included under Transit OVTT.

In-vehicle time for SOV trips (whether the chosen mode or an alternative) came from the CTPS regional network-based travel model set, and was available for the AM and PM peaks and three other off-peak time periods.

Shared Ride IVTT was calculated using the model-derived SOV times between origin and destination zones. These times were modified to reflect additional travel time needed to pick up or discharge passengers. These modifications were based on regression equations developed using the household travel survey.

To construct regression equations, reported travel times were compared for single versus multiple-occupant trips between the same origin and destination census tracts. Trip pairs with outliers (where SR time was more than twice the SOV time) were removed, as were pairs where the reported single-occupant trip was longer than that for the multiple-occupant trip. (Only one short HOV lane existed in the region in 1991.) A number of different regression equations were then developed using the relationship between reported SOV and SR times. Resulting R-squared

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[9] For rapid transit, we developed a table of running times between all stations on the Red, Blue, and Orange lines, based on information provided by the MBTA (running times plus dwell times). Running times were the same for all time periods - no adjustment was made for congestion in the MBTA rapid transit schedules. Green Line and Mattapan High Speed Line times were based on field work done by CTPS and the MBTA: the average of a few runs for each line produced a single daily travel time between each station.

Commuter Rail travel times were based on published schedules for April, 1992 and were therefore specific to the trip.

For bus lines, schedules in effect for Spring 1991 were used. Peak and off-peak schedules were generally available. Based on the scheduled arrival times at intermediate points, and the known distance between these points, average scheduled running speeds were calculated. Speeds multiplied by the distance between assigned on and off stops produced scheduled in-vehicle travel time for each traveler's bus path.

values were in the 0.7 to 0.8 range, and all models were significant.[10] These equations were then used to convert network SOV in-vehicle times to SR in-vehicle times.

All time variables are reported in minutes. The average IVTTs used, for chosen mode and alternatives, are shown in the table below.

Table 4-1 -- Average In-Vehicle Time - All Trips and Alternatives

	Mode of Trip		
Mode Chosen	**Transit**	**SOV**	**SR**
Transit choosers	19.5	18.3	21.7
SOV-choosers	37.1	19.2	22.8
SR-choosers	32.8	19.4	23.1

Note: Transit times shown are for just those trips that have a transit alternative.

These values would lead one to expect transit IVTT to be a significant factor in mode choice decisions.

4.2.2 Out-of-Vehicle Times - SOV/SR

Out-of-vehicle times for the SOV and SR modes were estimated from production and attraction terminal times for the zones associated with each trip. These terminal times came from the regional travel model, and generally represent the average time within each zone needed to reach the zone centroid, including the time to park/unpark and walk to/from a car. These times do not vary by time period. Terminal times in the Boston CBD and surrounding zones are generally five to seven minutes, while those in the suburban zones are more typically one or two minutes.

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[10] The regression equations used were as follows:

Multiple-occupants, Chosen Mode:

2 occupants

AM	Y=1.612514+1.08376X (X=single-occupant AM IVTT)
PM	Y=2.05328+1.049585X (X=single-occupant PM IVTT)
Off peak	Y=0.719697+1.21443X (X=single-occupant Off peak IVTT)
	3+ occupants
AM	Y=1.871388+1.055508X (X=2 occupant AM IVTT, calculated above)
PM	Y=2.184379+0.962427X (X=2 occupant PM IVTT)
Off peak	Y=1.811503+1.017497X (X=2 occupant Off peak IVTT)

Multiple-occupants, Non-Chosen Alternative
(Since the number of occupants for the non-chosen mode is unknown, an average of 2.5 persons per vehicle was used for the Shared Ride alternative.)

AM	Y=1.741951+1.069634X (X=single-occupant AM IVTT)
PM	Y=2.1188295+1.006006X (X=single-occupant PM IVTT)
Off peak	Y=1.2656+1.1159635X (X=single-occupant Off peak IVTT)

These terminal times were adjusted for the SR mode in the same way as for IVTT, to account for the extra time needed to drop off/pick up passengers.

4.2.3 Out-of-Vehicle Times - Transit Walk

This variable has two components, the time to access/egress each mode in the transit path, and the walk time within a transit facility. To estimate the access/egress time, distance was measured manually along streets from the midpoint of a geo-coded trip origin block to the boarding stop location, determined in the path choice process, or from the alighting stop to the destination block. Walk distances of up to two miles were allowed, as discussed later, to ensure that all "available" transit alternatives were considered. A walking speed of three miles-per-hour was applied to walk distance to estimate walk time.

Walk time within high-volume transit stations was estimated in the field during off-peak hours. Walks from all street-level access points to the midpoint of all platforms, and walks between platforms, were measured. Walk time also included, as appropriate, walk time from a parking lot to a station platform, or from a mid-level point in a parking garage to the platform. A default value of one minute was used where direct measurements were not made. For platforms at street level, without parking, this walk time was specified as zero.

Since no walk time information was collected in the household travel survey for transit choosers, both walk time components were calculated in the same way whether transit was the chosen or the alternative mode. The transit walk time variable in the data set is simply the sum of all access/egress and within-station walks in a transit path. Access, egress, and transfer walk components were available in the data set, and each was tested in some model specifications.

4.2.4 Out-of-Vehicle Times - Transit Wait

This variable measures the estimated wait time to access each mode in the transit path. Wait times for buses and rapid transit were set at one-half the headway. While there are some problems with this approach, there was no information readily available in Boston to modify these estimates. Subway headways came from departure time schedules by line provided by the MBTA. Published bus schedules were used for all buses. Both these sources provided us with the scheduled headway for a trip beginning at any time of the day.

For commuter rail, average wait times, by mode of access and by headway category, were taken from a 1992 Commuter Rail Passenger Survey.[11] Information on "usual" wait times was collected in the survey, for outbound trips from Boston during the PM peak period, and for both inbound and outbound trips in the off-peak. No data were collected for the inbound AM peak -- PM peak outbound data were used for the AM inbound. While using the survey results is inconsistent with the bus and rapid transit methods, the need for more accurate wait data for long-headway service was considered paramount.

Initially, bus and rapid transit wait times were constrained to a maximum of 10 or 15 minutes (depending on mode of access) to simulate known traveler tendencies to minimize wait time for scheduled services. However, imposing these constraints, while probably a good representation of average conditions, artificially implies that no waits over the maximum are possible, and probably distorts the resulting coefficients. For this reason, these maximums were ultimately removed.

In light of uncertainty about the proper specification of the wait time variable (see Issues below), a large number of wait-related variables were developed and tested.

- Wait as one-half headway, constrained - For bus and rapid transit, one-half of the MBTA scheduled headway, up to a 10-minute maximum for walk or drive access and a 15-minute maximum for bus, rapid transit, or commuter rail access. This longer (15 minute) cap was used because there is less control over arrival time when transferring from another transit line.

- Wait as one-half headway, unconstrained - No maximum wait time was imposed, to reflect some of the extra burden inherent in long headway trips. The largest wait actually used in the estimation file was 240 minutes (for a SR trip), and there were 36 waits over 60 minutes.

- Wait as one-half headway, initial wait constrained - This assumes travelers have control over their initial wait by using schedules, but transfer wait cannot be controlled by the traveler.

- Wait as the total headway, with or without an initial constraint - This is based on the theory that, at least after the initial wait, the traveler has no control over when the transit vehicle arrives, and may chose a transit trip based on this "worst case scenario".

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[11] All commuter rail lines in the Boston area were surveyed in April 1992. Over 8,800 completed surveys were received. One of the questions asked was, "Approximately how long do you usually wait for this train?" Mode of access and egress was also collected. This was the most extensive survey of commuter rail done in the Boston area in many years, and the only one where information on wait times was collected.

Analysis of the survey responses showed that average wait times varied significantly with access mode: those arriving at commuter rail by rapid transit or bus would wait on average two to three minutes longer than those who walked, while the average wait time of those who drove was somewhere in between. These results were consistent across train headways, but all wait times also increased as headways increased. We also found that average wait times never exceeded 15 minutes, and average wait times for walk and drive access never exceeded 10 minutes, regardless of headway.

- Long wait dummy - A variety of different dummy variables were defined, using the longest headway in a path, starting with headways over 30 minutes.

- Initial wait - The first wait for a transit vehicle -- both constrained and unconstrained versions were produced.

- Long initial wait - The number of minutes of initial wait time exceeding a threshold (tests started at 7.5 minutes). All wait minutes above this threshold were thought to be more onerous than those below, in effect producing a nonlinear initial wait variable.

- Transfer Wait - The wait for the second and all subsequent legs of a transit trip, constrained or unconstrained. Except for commuter rail, these wait times were developed independently of the access mode, since the Boston system does not include timed transfers.

4.2.5 Out-of-Vehicle Times - Transit Drive Access

Information on drive access came from the regional travel model set, using the station zone identified in the transit path coding. All transit trips were assumed to have drive access available at the home end of the trip, but must also have had a walk of less than two miles available at the destination to be considered as an available alternative. No travel time adjustments were made for shared-ride access to transit.

The average walk, wait, and drive access times for transit, SOV, and SR choosers are presented in the table below.

Table 4-2 -- Average Transit Out-of-Vehicle Times (minutes)

	Mode Chosen		
	Transit	**SOV**	**SR**
Walk	12.9	18.1	18.2
Total Wait (all trips)	8.6	35.1	27.6
Initial Wait	6.2	19.2	17.0
Transfer Wait	6.2	22.3	18.1
Drive Access	10.4	11.7	12.1

Note: Transit times are only for trips with a transit alternative, and transfer wait and drive access times are only for those trips with a transfer or with drive access.

While drive access times do not change much between transit as a chosen mode and as an alternative, transit choosers have shorter walks; and wait times, both initial and transfer, are shown to be far less for transit choosers than for those who chose to drive.

4.2.6 Issues

As part of the estimation of travel times for all modes, a number of decisions had to be made on the proper course of action. In order to ensure that the estimation file for our transfer penalty research was as accurate and bias-free as possible, a number of techniques were adopted which differ from the standard practices of which we are aware. We believe (based on extensive discussions with our Peer Panel) that these techniques are most appropriate for our research, and possibly all mode choice estimates. The questions raised and the reasoning behind our decisions are explained below.

4.2.6.1 Need for Hand-Coding of Transit Impedances

The first issue is whether manually-derived transit impedances result in better mode choice models than network-generated impedances. We had observed that even the most careful use of transit network- and path-building parameters still often resulted in insensible travel paths, and the impedances skimmed from these paths were often quite different from those associated with more plausible paths. We were also uneasy about the level of aggregation and abstraction in our network. We knew, for instance, that walk times from zone centroids to transit nodes masked important variations in actual walking time that we would want to capture in estimating a mode choice model. We feared that these abstractions might ultimately bias estimated mode choice model parameters.

We thought, therefore, that deriving paths and impedances manually and using them to estimate mode choice models would allow us to avoid these potential biases and ensure that our conclusions about transfer penalties were appropriate, rather than the product of network-related problems. We also assumed that findings about manual path coding would, in and of themselves, be of use to the modeling community. For these reasons, we spent a considerable amount of time deriving paths and impedances manually and using them to estimate mode choice models.

Ultimately, we did, indeed, find that hand-coded paths and impedances are very different from those generated by the transit network. The comparison between hand-coded and the regional model impedances is shown in Table 4-3 below. While average in-vehicle times are about the same for all three chooser groups, all other impedances are very different. Walk times show how large zones and centroids overstate walk access times to transit. Wait, auto access times, and cash fare differences probably reflect different path choices made by the regional model. Interestingly, these times result in an average OVTT/IVTT ratio of 1.28 for all regional model transit trips, versus 1.05 for the hand-coded. This is undoubtedly a major reason for the observed difference in the coefficients, discussed below, and suggests that the "true" ratio is much less than generally thought. The regional model's path choosing algorithms also produced fewer trips with transfers, although the average number of transfers when they were made is the same for both modeled and hand-coded paths.

A complete comparison of chosen paths was not done for the final estimation file (although it was for an earlier version), in part because of difficulties in defining exactly when a path is "different". However, of the 417 SOV and 190 SR trips with hand-coded transit alternatives, the regional model found transit paths for only 299 and 143, respectively. There were also 51 SOV and 20 SR choosers with regional model paths where no hand-coded paths were found, under very liberal definitions of when a transit path was available. Also, 45 surveyed trips that were actually made by transit were not given a path by the regional model.

Of ultimate importance in this project, the two different methods lead to different estimated model parameters, as will be discussed in Section 5.0.

Table 4-3 -- Transit Impedances: Hand-coded versus Regional Model

Transit Impedances (all times in minutes)	Transit choosers		SOV choosers		SR choosers	
	Hand-Coded	Regional Model	Hand-Coded	Regional Model	Hand-Coded	Regional Model
In-Vehicle Time	19.5	19.1	37.1	36.7	32.8	34.2
Walk	12.9	17.5	18.1	24.9	18.2	20.9
Initial Wait[12]	4.7	5.0	7.8	11.9	7.3	10.1
Transfer Wait (for trips with a transfer)	5.4	5.8	13.3	14.4	10.8	11.3
Auto Access Time (for trips with auto access)	10.4	6.1	11.7	9.5	12.1	9.6
Cash Fare	$1.10	$1.26	$1.93	$2.43	$1.80	$2.23
Average Number of Transfers	1.17	1.20	1.58	1.52	1.51	1.54
Number Trips with Transfers	201	228	301	205	110	95
Number Trips with Auto Access	60	36	109	72	47	35
Total Number of Transit Trips	536	491	417	351	190	163

4.2.6.2 What Should be the Maximum Walk Distance to Access Transit?

A major concern in the data development portion of this study was the effect that alternative definitions of transit availability have on estimated mode choice models. Perhaps the ultimate constraint on transit availability rests with the length of any walk access or egress. For home-based trips, for households with an auto available, the length of a walk from transit to the destination, in particular, will be crucial to the definition of transit availability.

The eastern Massachusetts household travel survey shows that many transit choosers walk longer distances than traditionally assumed. Table 4-4 shows that over 40 percent of all the actual transit trips in our estimation file involved a walk more than one-quarter mile, and over 10 percent involved a walk of more than one-half mile. This seems to have been an acceptable choice for the travelers, as transit choosers who had an auto available generally walked longer distances than transit captives.

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[12] All hand-coded wait times in this comparison are those based on the use of a 10-15 minute maximum cap.

The best available transit alternative for SOV/SR choosers generally involved even longer walks. While only one percent of transit choosers had a walk over one mile, almost nine percent of SOV/SR-choosers would require a walk of this length to access transit. Sixty percent of all the non-chosen transit trips would require a walk of at least one-quarter mile.

Table 4-4 -- Percentage of All Walks Greater Than a Certain Length

Length of Walk	Transit Choosers	Transit Choosers with an Auto	SOV/ SR Choosers
>1/4 mile	43.32	46.61	61.62
>½ mile	11.59	13.15	33.00
>3/4 mile	3.93	4.38	17.87
>1 mile	1.18	1.46	8.84
>1 ½ mile	0.39	0.53	2.55
Total access/egress walks	1018	753	1097
Total # transit trips	536	404	621

Rather than define transit as being unavailable if one of these traditional thresholds was exceeded, we decided that it was more appropriate to use the walk coefficients to show the impact of long walks on mode choice. In effect, the model does not attempt to understand what is an "available" alternative, but only to define when a long walk makes transit a poor (unlikely) choice.

At some point, all long walks become poor choices. When this occurs, adding trips with even longer walks should have no effect on the coefficient. As a practical matter, very long walks are also time-consuming to estimate. For these reasons, a series of models were estimated with increasing walk times, thereby increasing the number of trips with a transit alternative. Starting with trips where all walks were 0.25 miles or less, the maximum allowable walk to access transit was gradually increased to two miles. Table 4-5 below shows the results.

Where walk access is limited to one-half mile or less, the walk coefficient is positive. This is not surprising, since by restricting walks to a small distance, the implicit assumption is that length of walk is very important to the choice of transit. The positive, significant coefficient for 1/4 mile results from the fact that all 260 trips in the estimation file with a walk greater than one-quarter mile chose transit.

For mid-range walks, from 0.25 to 1 mile, the coefficient is small, unstable, and statistically insignificant. As walk distance increases, the coefficient tended to stabilize at the significance level shown. The wait and IVTT variables were also stable with these maximum walks, and the relationship among the variables appeared reasonable.

Table 4-5 -- Estimated Model Parameters by Maximum Transit Walk Access

	Maximum Transit Walk Access (miles)				
	≤0.25	≤0.50	≤1.00	≤1.50	≤2.00
Transit Choosers[13]	600	600	600	600	600
SOV/ SR Trips with Transit Alternative[14]	142	338	565	640	671
Total Walk Time					
Coefficient	0.1973	0.01875	-0.02461	-0.04621	-0.04896
t-statistic	3.3	0.9	-1.5	-2.8	-3.0
Total Wait Time coefficient[15]	-0.1637	-0.1528	-0.1526	-0.1484	-0.1503
Total Transit IVTT coefficient	-0.03461	0.00583	-0.05668	-0.01014	-0.0103
Rho-squared wrt zero	0.6923	0.6741	0.6810	0.6835	0.6853
Rho-squared wrt constants	0.3007	0.2986	0.3238	0.3286	0.3322

It is clear that transit choosers sometimes walk long distances to access transit, and eliminating these choices from the estimation file eliminates real transit behavior. Yet restricting the walk distances of only SOV/SR-choosers produces illogical and unstable coefficients. As a response to all these considerations, a maximum walk length of two miles was used to define an available transit alternative through all the later stages of the transfer penalty research.

4.2.6.3 What is the Proper Definition of Wait?

In the course of developing accurate transit wait times, it became clear that two questions needed to be addressed:

- Is one-half the scheduled headway the appropriate approximation for the average wait time a tripmaker will face?
- Should there be a cap on the maximum wait?

A variety of specifications were developed to properly understand the role of wait times in mode choice decisions. Initial versus transfer waits, dummy variables for long waits, and wait as a step function were all evaluated. However, the impacts of long waits cannot be assessed if wait times are capped, and at least the relative importance of all wait times will depend on the relationship between scheduled headways and average wait times.

[13] All transit choosers have a transit alternative, regardless of the actual length of the access walk.

[14] Of the 862 SOV/ SR choosers, 671 have a transit alternative. That is, they have a walk of less than 2 miles at the work end of the trip, and an auto available at the home end. Note this model was estimated using a 1462-trip file, which included trips with missing incomes and with OVTT/IVTT > 10.

[15] Total Wait coefficient is always significant at the 95% confidence level, Total Transit IVTT never is.

Cap on Wait Times

Initially, bus and rapid transit wait times were capped to a maximum of 10 (for walk or drive access) or 15 minutes (for transit access). The intent was to simulate known traveler tendencies to minimize wait time for scheduled services. However, in deciding whether to use transit, it seems at least possible that decisions will be made on the basis of what is the worst-case wait; but from a model estimation standpoint, capping maximum waits removes long waits from the choice set.

The wait variable was not particularly significant in early incarnations of the model, and the cap on maximum wait time seemed a likely cause. As a result, tests on the impact of removing these caps were conducted. Since persons should generally have more control over their initial wait time than any subsequent transfer wait times, changing these two values was evaluated separately.

The table below shows how constraining initial wait to 10 minutes and transfer wait to 15 minutes impacted the impedances used in model estimation.

Table 4-6 -- Capped versus Uncapped Wait Times

Average Wait Time per Wait (minutes)	Transit - Choosers	SOV - Choosers	SR - Choosers
Initial Waits Capped	4.7	7.8	7.3
Initial Waits Uncapped	6.2	19.3	17.2
All Waits Capped	4.7	8.1	7.2
All Waits Uncapped	5.9	16.5	14.8
Number Waits Capped	109	394	148
Total Number of Waits	771	901	621

Not surprisingly, initial uncapped shows a bigger increase over capped than does the all waits category, since the initial cap was tighter (10 minutes). Single-occupant vehicle and SR choosers both had larger numbers of capped waits and much greater wait times than transit.

Table 4-7 shows the results when initial waits are capped (transfer wait caps had been removed much earlier in the process, and no capped transfer time values were available in the estimation file used in this analysis). The coefficients for initial versus transfer wait for capped values were opposite our expectations, and seem to result from scaling, due to the greater magnitudes of transfer wait impedances in this mixed file. When all caps were removed, transfer wait appears to be twice as onerous as initial wait, with about the same average values, while the walk and IVTT coefficients remained relatively stable and significant.

Table 4-7 -- Estimated Model Parameters, Uncapped versus Capped[16]

Variable	Coefficients (t-statistic) Initial Wait Capped	All Waits Uncapped
Total Initial Wait	-0.1849 (-3.8)	-0.0551 (-3.1)
Total Transfer Wait	-0.1050 (-4.2)	-0.1059 (-4.2)
Total Transit IVTT	-0.0411 (-2.7)	-0.0454 (-2.9)
Total Walk	-0.0537 (-3.5)	-0.0431 (-3.0)
Rho-squared wrt zero	0.6822	0.6888
Rho-squared wrt constants	0.3259	0.3235

As a result, all caps were ultimately removed from the final estimation file. This is much the same logic that applied in the maximum walk discussion above.

One final point. The length of the average wait was not a consideration in the decision on whether transit was "available". When constraints were used, this was not a problem since there were no long waits. However, as constraints were removed, some very long transit wait trips were now defined as available. Rather than simply accept all long wait trips, the OVTT/IVTT ratio was used to define an outer limit on availability (see discussion in Section 4.2.6.4 below).

Wait as One-Half Headway

Average wait time as one-half the headway is the convenient, traditional method of estimating this variable. As long as service is on-schedule and passenger arrivals are random it should be a fairly accurate approximation. While we do not know if passengers arrive randomly, it is clear that during peak, congested periods, many transit vehicles do not arrive on schedule or at regular intervals. The well-known phenomena of "bus bunching" occurs.

It has been suggested that average waits, during congested periods, will actually be 60-70 percent of the scheduled headway[17]. There was no direct data in the Boston area on which to estimate the actual average waits, but we were able to investigate how different definitions of the average wait changed the ultimate values of the wait impedances and the resulting model coefficients.

Average wait was estimated as one-half the headway and the entire headway, as shown below. When the wait equals the headway, coefficients doubled (for both capped and uncapped scenarios), were equally significant, and had no impact on the walk and IVTT coefficients.

[16] Allowed wait times are based on ½ the scheduled headway. All other notes same as footnote 15.

[17] According to Bob Harvey of the Peer Panel, Seattle is using congested average wait times of 60-70% of the scheduled headways, based on surveys conducted in the region.

Table 4-8 -- Estimated Model Parameters For Alternative Definitions of Wait[18]

	Initial Wait Capped		Initial Wait Uncapped	
	½ Headway	One Headway	½ Headway	One Headway
Total Wait Time				
Coefficient	-0.10960	-0.05192	-0.05586	-0.02793
t-statistic	-3.9	-3.6	-3.5	-3.5
Total Walk Time coefficient	-0.03947	-0.0356	-0.03034	-0.03034
Total Transit IVTT coefficient	-0.025	-0.0264	-0.0352	-0.0352
Rho-squared wrt zero	0.6843	0.6840	0.6828	0.6828
Rho-squared wrt constants	0.3304	0.3296	0.3271	0.3271

If the average waits should be 60-70 percent of headway, it is clear from these results that the coefficients will simply increase accordingly. Increasing the wait time just for peak trips, or including a variable for the increase over the "expected average wait" was not investigated, but could well have the result that increased wait times lead to increased transit use (since wait times will be greater in peak periods, when transit use is highest).

4.2.6.4 Should There be a Maximum Ratio of Out-of-Vehicle to In-Vehicle Travel Times?

If Out-of-vehicle time really is more onerous than in-vehicle time, there should be some point at which the combination of walk, wait, and drive access times preclude a transit trip, regardless of how fast the line-haul portion of the trip is. Transit users without an alternative would be the only expected exception. For this reason, the ratio of OVTT to IVTT was developed as a variable to be evaluated.

In the final estimation file, five of 536 transit choosers have an OVTT/IVTT ratio >10. Of these, two have no auto in the household, and therefore have no drive alone option. However, four of the five have IVTT of about two minutes, and the fifth has an IVTT of four minutes, which indicates a walk trip might be an alternative for all of these. However, all were subway trips, so the short in-vehicle time is not associated with a short distance trip. All five also had cumulative walk times of over 10 minutes. Four of the five trips were paid for with a pass, so the marginal cost of these trips might be considered zero. The fifth trip paid full fare but had no vehicle available. Age did not seem to be a factor in any of the five trips, as the oldest person was 50 at the time of the survey.

[18] All IVTT and Walk coefficients have t-statistics of 1.6 or more. All runs use 1457 trips, the 1462 trip file minus 5 transit choosers with OVTT/IVTT >10. There were no transfer variables in these runs.

An additional 14 transit choosers had a OVTT/IVTT ratio greater than 5, almost all with short IVTT. Again, almost all trips were via subway. Of the 14 trips, nine were made with a pass, seven had no vehicle available, and only one had a cumulative walk time less than 10 minutes.

For the SOV/SR choosers, 19 alternative transit trips had a OVTT/IVTT ratio > 10. These were generally similar to transit choosers, with short IVTT and long walks. However, half also had waits of 10 minutes or more, and seven of the transit alternatives would involve buses.

Ultimately, we decided that some ratio was necessary, and a ratio greater than 10 was used as the cutoff. The five transit and 19 SOV/SR trips were removed from the estimation file.

4.2.6.5 What are the Proper Travel Times for Shared Ride Trips?

If travel costs are reduced for shared ride trips but travel times remain unchanged, then the assumption is that travel time plays no role in SR mode choice (either because there is no increase in time, or because SR trip-makers do not care about the extra time). However, by definition, it must be true that all but one of the shared-riders will have a longer travel time (although not so long that it may not be lost in the intrazonal times). Model estimation using longer times should tell us whether they care.

The method we employed for SR times is a preliminary attempt to implement these considerations. Clearly, the method used is not statistically valid, as the results are biased to produce longer SR times. However, given the clear grouping of reported travel times in five minute increments, the availability of many 5-10 minute intrazonal travel times in the regional model, and the expectation that much of the additional SR times could be five minutes or less, it was not reasonable to expect the available data to precisely calibrate the additional SR times. Rather than simply assigning extra time to each SR trip, the regression equations assign longer absolute SR increments to longer trips, but with a decreasing percentage of total time. The results are hardly ideal, and additional research in this area would be most welcome. Ultimately, for the transfer penalty research, we do not believe these problems invalidate our conclusions.

4.2.6.6 Use of Network Rather than Hand-Coded SOV/SR Times

Initially, we had hoped to use hand-coded SOV and SR paths and impedances; however, this was not done for a number of practical reasons. Path choice, for example, would involve evaluating many alternative paths, as the entire roadway network is available for selection. Picking the minimum path, however defined, is what the regional model already does.

Once the auto paths were selected, impedance estimation would also be problematic. Real travel times or speeds are not available for roads below the major arterial class, and where available, they are only for a limited number of time periods. Hand-coding of auto impedances to reflect "expected real" times would therefore have required a major data collection effort.

For this project, paths and associated times come from the regional travel model which uses an unmodified BPR curve to calculate speeds and an equilibrium-constrained assignment routine.

As with most regional models, lower functional class roadways are omitted from the network. Very low travel speeds are rarely estimated from these types of models. It is likely that auto IVTT would be very different if accurate hand-coding could be done, but ultimately it is unknown how much error is introduced into the estimation process by using network data. However, for this project, it was felt that impacts on any transfer penalty findings would be small.

4.3 Travel Cost Variables

Information on three types of travel costs was estimated:

- transit fares,
- parking costs,
- auto operating costs.

All costs would be considered out-of-pocket costs by users of the transportation system. No information on fixed costs, e.g., the costs of owning an auto, was used in model estimation, and all costs are in 1991 dollars.

Parking costs for SOV/SR choosers, and fares and transit parking costs for transit choosers, were generally obtained from the household travel survey responses, except where this was inconsistent with other known information about the travel path. Auto operating costs were always based on travel distances generated by the regional model. No information on tolls was collected or estimated.

4.3.1 Transit Fares

Once the transit path was determined, the assigned transit fare was the one appropriate to that specific trip. This is complicated in Boston by the existence of different inbound and outbound fares, and by the extensive use of transit passes and other discount payment plans. This led to the development of a number of alternative transit fare variables, some of which were used in combination. All fares and discounts were those in effect in 1991.

The following variables were entered into the estimation data set and tested.

- Cash Fare - That required for the entire one-way transit trip, without discounts. On some trips, the reverse trip would have a different cash fare, but the cash fare specified was that appropriate for the particular trip. The average cash fare is $1.10 for the 536 transit choosers in the estimation file, but $1.92 for the 607 SOV/SR choosers with a transit alternative.

- Pass Fare - Where a transit pass or other discount (student, senior, etc.) was used by a transit chooser, pass fare was based on this information. For all other trips, the discounted cost of a trip was estimated based on the minimum pass needed to complete that entire trip, including transfers. The price of the monthly pass used was converted to a per-trip cost based on an assumed 20 work round trips (i.e., monthly pass cost/40). Of the 536 transit choosers, 57 percent used some type of discounted payment option, with an average estimated savings of $0.19 per trip.

- Average Fare - Calculated as the average of the cash fares on each leg of a round trip.

- Fare - A mixture of cash and pass fares, with transit choosers given the fare they paid for the path chosen (as long as it was possible for that path), while SOV/ SR-choosers were given full cash fare for their transit alternative The initial model specifications used this fare variable, which was designed to capture the influence of discounts on mode choice decisions.

- Transfer Fare - The amount paid for the second and all subsequent transit legs, based on the required cash fare. "Free" or discounted transfers, due to the presence of a pass, were not used for transit choosers, since it is unknown whether SOV/ SR choosers would have a pass available, or would chose to purchase one, if they chose transit. Even for transit choosers, the allocation of costs between the initial and transfer legs is a problem unless cash fare is used. In the Boston (MBTA) system, subway-to-subway transfers are generally free, while all other transfers are not. Transfer fare is also highly directional: a bus-to-subway trip would not cost the same as a subway-to-bus trip.

- Initial Fare - the cash fare for the first leg of any transit trip.

While all these versions of fare were tested in many different model specifications, ultimately cash fare (divided by income) was used for the final model estimation. Cash fare/income was chosen for both theoretical and practical reasons. Cash fare seems to be the most reasonable of the fare options, for reasons discussed in section 4.3.4.1 below, and dividing by income is an accepted normalizing practice. Cash fare/income was one of the few fare specifications which resulted in stable, significant, transfer penalty coefficients.

4.3.2 Parking Costs

Auto accessibility to transit can be influenced by parking availability at transit stations. Auto availability for work trips may be constrained by parking availability at the destination, particularly in the CBD. In both cases, demand can sometimes exceed current supply in the Boston region. However, for this study, parking was assumed to be available at any transit station or traffic zone appropriate for the trip in the estimation file.

To convert parking costs to a per-trip basis, daily parking costs for home-based work trips were divided by two. Monthly parking costs were converted to daily by assuming 20 working days per month.

Parking costs could be incurred at transit park-and-ride lots for transit trips, or at a parking facility at the work end of a SOV/SR trip. Parking costs for SR trips were shared among all passengers, either the known number or the home-based work average shared occupancy of 2.4 persons. All transit parking costs were always assigned to the transit trip-maker, since the number of other persons sharing drive access was unknown. Three different parking variables were specified and used in the final estimation file.

- Parking for Transit Access - Once the transit path was known, the park/ride lot used for drive access to transit was known. No drive access trips to subway or commuter rail were assigned to stations without paid parking lots, and all trips were assumed to park in MBTA, rather than private, lots. Transit parking cost was the daily, undiscounted fee for the lot as of 1991, divided by two. Drive access to bus was assumed to use free, on-street parking.

- Parking for Auto Trips (Single-occupant Vehicles) - Parking costs for SOV choosers were available from the household travel survey, and were used for these trips. Not unexpectedly, only the Boston CBD and a few neighborhoods in the adjacent communities had any significant numbers of paid parkers. Most paid parking was in lots or garages, rather than on-street, and was divided about equally between daily and monthly payment. Yet, except in a very few CBD zones, there was more free parking (even in lots/garages) than paid[19]. Where the trip in the estimation file was work-to-home, the parking cost reported for the home-to-work trip, if available, was used. Again, all daily costs were divided by two.

  When SOV was the unchosen mode, the parking cost was the neighborhood average parking charge in Boston and Cambridge, and the city or town average elsewhere. The average was calculated from all work trips in the household travel survey where a vehicle was parked (and transit was not used). The average parking cost in the Boston CBD (defined as those areas where there was more paid than free parking) was based on the amount <u>paid</u> to park in a garage or lot (i.e., free parking excluded). The assumption here is that transit-choosers will not have free parking available in the CBD. The average cost elsewhere was the average of all parked vehicles, excluding those parked at residences. It was decided to use zonal averages rather than Monte Carlo techniques because we believed that the lack of variability in the zonal averages was less important than the potential error introduced to fundamental relationships by combining randomly assigned and actual answers.

- Parking for Auto Trips (Shared Ride) - Parking costs for the shared ride choosers were those from the survey, while those for the SR alternative were estimated exactly as for the SOV alternative. All parking costs were then divided by 2.4, which is the average number of occupants for all shared ride home-based work trips in the survey.

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[19] Overall, 90.5% of travelers who parked at a lot/garage did so for free. Where Boston was the destination, less than two-thirds (63.7%) parked free at lot/garages. In Cambridge, 82% parked for free.

Slightly more than half (56%) of all parkers paid a daily rather than monthly fee. Monthly parkers paid much less on a daily basis than daily parkers, when a 20 day work month is assumed (and parking is used all 20 days). On average, it cost $64.30 to park a car monthly in the region (when parking was paid for at all), or $3.22 per day. The average daily parking fee in the region was $5.70. For Boston, these figures are $80.60 monthly, $4.03 per day and $6.44 per day, respectively.

The average parking costs used for the trips in the estimation file are shown below. Most transit choosers had destinations in areas where paid parking would be required if they chose to drive.

Table 4-9 -- Parking Costs in Estimation File

	Transit Trips		SOV Trips
	Number Parked	Average Cost[20]	Average Cost
Transit Choosers	60	$0.53	$2.32
SOV/ SR Choosers	154	$0.41	$0.14

4.3.3 Auto Operating Costs

In addition to transit fares and parking costs, operating costs had to be estimated for all SOV/ SR trips. No information on these costs was collected in the household travel survey. Rather, this cost was calculated as the distance driven, in miles, times a cost of 9.8 cents per mile, which is the AAA nationwide average for the variable cost (including the cost of gas, oil, maintenance, and tires) of operating a passenger car in 1991. No more specific figures were available for Boston or the Northeast, and the relationship between cost and distance was assumed to be linear. Toll costs were not included.

The auto travel distance was taken from the regional travel model, for each trip origin and destination zone-pair, for five time periods. Drive access distance for transit trips was calculated between the home zone and the appropriate transit parking zone. The average trip length for a SOV/ SR trip was 10.5 miles, while that for the transit choosers' drive alternative was 7.1 miles. Travel distance was not increased for shared ride trips, unlike travel time, and operating costs for the shared ride mode were simply single-occupant vehicle costs divided by the average shared work trip occupancy of 2.4.

4.3.4 Issues

4.3.4.1 Use of Discounted Versus Cash Fare

For any transit trip, the cash fare required can be determined once the path is selected. However, more than half of all transit trips in the estimation file were paid for using some type of discount option. For regular work commuters, this reduces the average cost of a transit trip to well below the cash fare. More importantly for this project, in Boston, where transfers between modes are not free, possession of the appropriate monthly pass reduces or eliminates the monetary cost of transfers. Of the pass users in the estimation file, 33 percent made a transfer that would have required a payment, while only 16 percent of those who paid cash made such a transfer.

Simply using cash fare for transit would remove all impacts of the monthly pass from further analysis, and would not be directly comparable with the reported costs for the transit choosers.

[20] Twenty-two transit choosers and 47 SOV/ SR choosers parked for free.

Assigning transit users only cash fares would have ignored the fact that some users only use transit because they can get a discount, or would not make a transfer without a pass that makes it free. Using pass fare for all would pose similar problems. Trying to use Monte Carlo techniques, for example, to assign pass fares to 57 percent of the non-choosers would have mixed passes with possibly wrong attributes of actual pass buyers, and would have assumed that the availability of discounted fares has no impact on mode choice and transfer behavior.

Fare was the original variable used in model specifications. Mixing discounts for transit choosers with no discounts for SOV/ SR choosers makes the discount an important consideration in mode choice, an initially appealing assumption. Using fares for transit choosers implies that there is some cost savings to passes that non-choosers ignore or do not know about. However, giving SOV/ SR choosers no reductions for their transit alternative overstates the importance of the discount for transit choosers. In addition, using any discount option makes allocating costs between initial and transfer fares somewhat arbitrary.

There does not appear to be one correct answer to this problem using the data we had available. For the final series of estimates cash fare was used, for reasons of consistency and to eliminate the impact of discounts as a confounding factor. The use of cash fare also allows transfer fare to be evaluated, which could be a significant variable in the existence of a transfer penalty. And using cash fare, which maximizes the dollar cost of a transfer, would tend to reduce the importance of an independent transfer penalty, which was nevertheless found to be significant. Presumably, if the correct mix of discounts and full fares could be determined, the "true" transfer penalty would be even larger.

4.3.4.2 Problems with Transfer Costs

This research did not find any penalty associated with the extra cost of transferring in the Boston system. However, it is not clear whether this is because there is no penalty associated with this extra cost, or whether the complexities of the Boston transit pricing policies prevented us from detecting it.

Unlike transit travel time impedances, where we could assign a precise average walk, wait, and in-vehicle time to each trip, the expected cost of a non-chosen transit trip was difficult to estimate. While the required cash fare, including the cost of any transfers, is known, the actual fare a tripmaker would pay depends on whether they would take advantage of the numerous discounts available. These discounts not only reduce the average cost of any trip, but they may also significantly reduce the cost to transfer.

Since the transit alternatives for SOV and SR choosers were chosen without regard to cost, discount prices do not affect their transfer behavior in our estimation file. They could, however, because more than 50 percent of transit choosers used some type of discount fare. Since multiple paths are available for many of these trips, the reduced cost of transferring could allow tripmakers to choose less direct, but cheaper, routes.

Besides influencing path choice, available discounts could influence mode choice as well. Transit choosers could have selected this mode because the discount was available to them: at full fare they would have chosen SOV or SR. We have no way of knowing how many of our transit choosers would have made this decision, but for those who did, and whose trips also involved a transfer, some penalty for the cost of a transfer would also be appropriate. Using full cash fares allows us to estimate an absolute transfer penalty, but does not provide information on whether an additional penalty should be associated with the cost of transferring.

4.3.4.3 Determining the Correct Parking Costs

While the household travel survey did ask for any parking costs incurred, no information was collected on the parking location or the cost to park for alternative modes. By assuming that all parking occurred near the destination (not necessarily true in the Boston CBD), the average parking cost per vehicle and per person was developed from the household travel survey by traffic zone and by neighborhood (although data is missing for many of the cells at the zonal level). This was used as the parking cost for SOV and SR alternatives when they were the non-chosen modes. As with the transit fares, inconsistencies between costs for the chosen and non-chosen modes arose from this convention.

Many of the parking costs for SOV/ SR choosers were free, even in the CBD. By using the zonal averages, most SOV/ SR alternative trips were forced to incur some cost for parking. In the Boston CBD these costs were especially large, since all free parking was removed from the average. Nevertheless, for CBD transit choosers, the implicit assumption is that parking cost matters. The alternative of assigning no parking cost in the CBD was rejected.

4.3.4.4 No Information on Automobile Tolls

No information on tolls paid for auto trips was collected in the household travel survey, although there are toll facilities entering Boston from the west and north. Travel paths for auto trips were also not available from the household travel survey. Network-derived travel paths, from the regional travel model, are based on minimum travel times: cost is not a factor. Toll costs could simply be added to all network-determined paths which use toll facilities, but this implies that no path diversions are made to avoid tolls.

Because estimating tolls would have required assumptions about path diversion behavior about which we did not have information, no toll costs were included in the estimation files. Assumptions which we might have made, such as minimizing travel times regardless of cost, or diverting from toll roads when only five minutes were added, would have implied a specific value of time and biased the results of the other time and cost variables towards this figure.

In the final analysis, while tolls undoubtedly impact travel paths, and possibly mode choice, we did not believe they would have any impact on transit transfer behavior.

4.3.4.5 Limited Use of Fare in Path Determination

As explained earlier, minimum time, not fare, was used to determine transit paths, for the most part. For transit choosers, information reported on fare paid was used to help identify the actual path taken. However, when transit was the alternative mode and the path was unknown, fares, including cost of transfers, were not generally used in determining paths, except for a few expensive commuter rail options where bus or subway alternative paths were available.

Removing cost from the path choice decision limits its impact to mode choice. As discussed elsewhere, ultimately what we investigated was the existence of a transfer penalty for mode choice, not path choice.

4.4 Transfer Variables

The ultimate objective of this research was to determine whether the act of transferring itself carries a penalty, above and beyond any disutility associated with the additional time and cost needed to transfer. To search for this penalty, a great deal of information about the existence of a transfer and the conditions under which it was made was developed. This section describes the varieties and sources of this information.

Whether or not transfers are made is a direct consequence of the transit path chosen. The path was generally available from the household travel survey for transit choosers, but had to be inferred for all other trips. The challenge in this case was to develop transit paths which do not automatically bias the transfer penalty research.

Our response to this challenge was to develop paths which were "transfer-neutral": where travelers' response to transfers was not considered at all. If more than one transit path seemed reasonable, the one with the shortest overall travel time was simply selected, regardless of the number of transfers (or cost, for that matter). In Boston, for work trips, minimizing trip time will generally minimize transfers, the only exception being transfers from bus to subway, where frequent and direct service makes this a favorite path.

At first glance, these "transfer-neutral" paths seem anything but, and they may in fact be underestimating the impact of transfers on <u>path</u> choice, particularly for long headway services. In reality, most path choices, for work trips, had similar numbers of transfers; and few major tradeoffs, between transfers and walk or wait time, for example, were available for these trips.

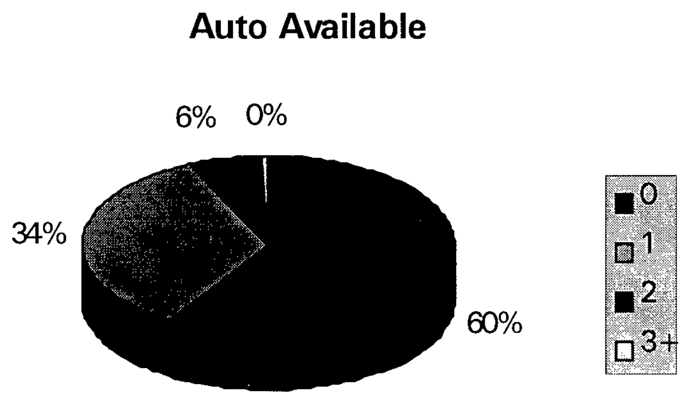
However, for mode choice, the importance of transfers seems clear from the estimation file. In the table below, over 60 percent of all the actual transit trips in the estimation file had no transfers, and only six percent had more than one. For trips where SOV and SR were the chosen modes, the transit alternative is much more likely to require a transfer, and, in over 20 percent of these alternatives, two or more transfers. The "transfer-neutral" path choice decision rule produced a clear distinction at the mode choice level.

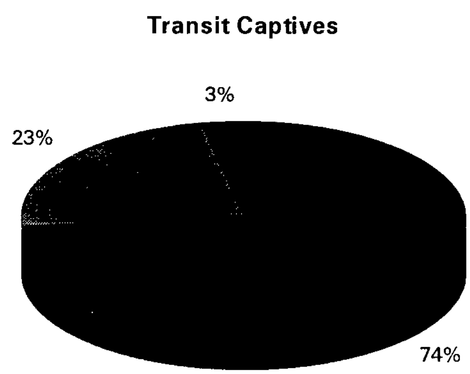
Table 4-10 -- Mode Chosen by Number of Transfers

Mode Chosen	Number of Transfers			
	0	1	2	3+
Transit choosers	335	169	30	2
SOV-choosers	241	156	117	28
SR-choosers	149	66	32	12

However, this distinction may be somewhat undercut by the charts below, which show that transit choosers with an auto available had a clear tendency to transfer more than transit captives.

Figure 4-1 -- Number of Transfers - Transit Choosers Only





This does not seem to be primarily a low income phenomena, as more than half of these captive trips come from households with an income between $20,000 and 40,000. Rather, the choice not to own a car may be related to living near good, "transfer-free" service.

The transfer variables used in this study include the existence and number of transfers, the type of transfer, and the conditions under which transfers were made. Each will be discussed in turn.

- Transfer Dummy - simply whether a transfer occurred at any stage in the trip, regardless of the quality of the transfer. Transfers between an auto and transit were not considered in this study.

- Number of Transfers - a simple count. There was no limit placed on the number of transfers possible, but no trips with more than four were found.

- Type of Transfer - a description of the modes in the transfer, based on the notion that some modes and trip characteristics are more likely than others. Six categories were used: bus-to-bus, subway-to-subway, subway-to-rail, and other were all non-directional. In addition, it was felt that transfers from low frequency to high frequency services could be different from the reverse, so any other mode-to-bus and bus-to-any other were categorized separately. This was not done for rail-to-subway versus subway-to-rail on the assumption that rail waits will be minimized through the use of schedules. Each transfer in the path was assigned to one of these six categories, and dummy variables for each category were used in model estimation.

- Sheltered Transfer Dummy - Sheltered transfers were assumed to be preferred to (or at least different from) unsheltered. Knowledge of the MBTA system allowed us to determine if each transfer was sheltered or unsheltered. The number of unsheltered transfers then became one of the variables tested.

- Stairs/No Stairs - Based on the assumption that the need to traverse stairs might further discourage transfers, each transfer was assigned as either stairs or no stairs. Variables were then developed based on the number and existence of stair transfers.

The numbers of different transfer types available in the estimation file are summarized below.

Table 4-11 -- Number of Transfers of Different Types

Type of Transfer	Transit choosers	SOV-choosers	SR-choosers
Bus - Bus	8	95	24
Other - Bus	54	115	37
Bus - Other	65	80	38
Rapid Transit - Rapid Transit	62	78	33
CRR - Rapid Transit	42	83	30
Other	0	10	4
Number of unsheltered transfers	74	250	80
Number transfers with stairs	172	305	112
Total number of transfers	235	474	166

There seems to be a tendency for the SOV/ SR alternatives to have somewhat poorer quality transfers, as the percentages of unsheltered transfers and transfers involving buses are much higher than for transit choosers. However, none of these quality variables were found to be significant in model estimation.

4.5 Socioeconomic Variables

4.5.1 Household Income

This information was collected for each household that participated in the survey; individual incomes were not elicited. The survey asked which of six categories best matched the annual household income:

1=$1 - $19,999,
2=$20,000 - $39,999
3=$40,000 - $59,999,
4=$60,000 - $79,999,
5=$80,000 - $99,999,
6=$100,000 or over

These were later reduced to four categories, with four, five and six collapsed into one $60,000-and-above group, as very few households with incomes in categories five and six were found in the survey.

Dummy variables were established for each of these four categories, and low and high incomes were found to be important, for transit and SOV mode choices, respectively, in most of the early model specifications. In these specifications, fares, parking, and operating costs were not adjusted for the income of the tripmaker. However, as shown in Table 4-12, once transit is chosen, low income users are less likely to transfer than those from higher income households.

Costs were divided by income in the final model specifications. Alternative specifications divided costs by the square and the square root of income, positing differing patterns of incomes' impact.

Since only household income categories were available, generalizations were necessary to develop estimates of the relevant annual income for each tripmaker. Since individual incomes were not available, household incomes had to be applied, and rather than try to estimate a specific income within each category, based on correlations with such variables as number of workers, household size, and auto ownership, the midpoint of each category was simply used as the income for all households in that category.

4.5.2 Age and Gender

The year of birth was available for all household members over five years of age, and gender was also determined for all tripmakers. Gender seems to have some relationship (not necessarily causal) to transfer behavior, age less so.

Although more females than males chose transit trips, males were much more likely to transfer, as the table below shows. Transit alternatives assigned to SOV/ SR choosers exhibited the same tendency. The age-related trends are less clear, as the 46 to 64 age group has the greatest tendency to transfer, and those aged 30-45, the least. This finding may be due to the particular grouping used, but alternative groupings produced no more consistent patterns.

Table 4-12 -- Transit choosers by Socioeconomic Categories

	No Transfers	One or more Transfers
Income 1	40	21
Income 2	102	50
Income 3	71	55
Income 4	122	75
Male	136	114
Female	199	87
Age 18-30	128	72
Age 31-45	144	76
Age 46-64	49	46
Age 65 and above	12	7
All Transit choosers	335	201

4.5.3 Number of Workers and Vehicles

Both the number of workers and vehicles per worker were important variables in transit mode choice. Both variables were available at the household level, along with work characteristics (full versus part-time) for each worker. Vehicles per worker, as a surrogate for auto availability, was divided into three groups: households with 0.5 or fewer vehicles per worker, those with one or more, and all those in between.

4.5.4 Population and Employment Density

Density, in employees or population per acre, was obtained for each zone from the regional travel model. This allowed both production and attraction zone densities to be assigned to each trip. It was expected that production population density and attraction employment density, in particular, might be important for mode choice decisions. However, the detail we provided for transit impedances could reduce some of their importance, since they are generally seen as surrogates for level of transit service.

Employment density at the attraction zone and population density by production zone both seem to be very significant determinants of mode choice, based on the trips in our estimation file. Almost 78 percent of all SOV trips, and 68 percent of the SR trips were attracted to zones with employment densities of less than 10 employees/acre, but only 11 percent of transit users were going to those zones. In contrast, 59 percent of all transit trips were attracted to zones with 100 or more employees/acre, while only nine percent of all non-transit trips went to these high density zones.

The population density of the production (home) zone is also significant. Fully 70 percent of all SOV and 66 percent of SR trips came from zones with populations less than 10/acre, while only 28 percent of transit users did so. When these two variables are cross-classified the trend is reinforced: high density population-to-high density employment trips use transit overwhelmingly (87 percent of all such trips), while low density-to-low density trips almost never do (3 percent).

4.5.5 CBD Dummy

The Boston CBD is generally defined in our modeling efforts as the 60 zones on the Boston peninsula bounded by Massachusetts Avenue. As with density, this is a surrogate for transit quality, but is also the area where most significant parking charges are found.

4.5.6 Issues

4.5.6.1 Income Based on Four Income Categories

The distribution of income within categories is unknown. Since income was found to be an important variable, particularly relative to travel costs, the use of very general, household-based estimates was cause for concern. Income could be inaccurate by as much as $10,000 (more in the high income category), and the true tripmaker income could produce different results. However, given the information available, there does not appear to be any way to test what these differences might be.

Using the midpoint was essentially the same as using the group median, as the results below show.

	Midpoint	Median[21]
Income 1	$10,000	$9,900
Income 2	$30,000	$30,000
Income 3	$50,000	$48,900
Income 4	$87,900	$80,500

Since the household travel survey sample design was intended to replicate eastern Massachusetts socioeconomic characteristics, using the midpoint is an appropriate representation of the median household income of all surveyed trips. Other approaches, which estimate an income based on other household attributes, are promising, but unproved and time consuming.

[21] The median is calculated using 1990 Census results for eastern Massachusetts.

5.0 RESULTS

This section contains a presentation of all our major results. They are divided into two categories. The first includes those related specifically to the transfer penalty issue, while the second includes the other findings generated during the course of the research.

5.1 Findings About Transfer Penalties

These findings are subdivided into four categories that relate to the ways in which transfer penalties were investigated. Table 5-1, referred to below, contains the "best" model estimation results. That is, this model, among the many estimated, best illustrates some of our findings. It is not necessarily a model we would recommend for forecasting; rather, it is a research-oriented model.

5.1.1 Transfer Penalty as a Dummy Variable

The major finding emerging from this project is that there is a detectable transfer penalty for work trips in Boston. It is most apparent as a dummy variable representing whether or not any number of transfers are required for a trip. The findings are stated in more specific terms below.

- *There is, in fact, a "transfer penalty" detectable at the mode choice level in Boston area home-based work trip-making.* That is, when a dummy variable is specified to indicate whether or not a transit path contains one or more transfers, that variable is significant at about the .80 to .85 level, depending on the specification. (See Table 5-1 below.)

Table 5-1 -- "Best" Specification Results

Variable	Coefficients		
	Transit	Drive Alone	Shared-Ride
Transfer Dummy	-.545[b]	-	-
In-vehicle time	-.042	-.118	-.117
Walk time to transit	-.033	-	-
Initial wait time for transit	-.055	-	-
Transfer wait time for transit	-.100	-	-
Auto access time to transit	-.139	-	-
Out-of-vehicle time	-	-.309	-.193
Park. & operating cost/income	-1.729	-1.729	-1.729
Transit cash fare/income	-.828[b]	-	-
Workers/household	-.660	-	-
Vehicles/worker <= 0.5	2.133	-	-
Vehicles/worker >= 1.0	-	1.093	-
Pop. density, production zone	.027	-	-
Constant	-	1.964	.634[a]
[a] Significance below .85 level [b] Significant at .85 level All others significant at .95 level	Rho-squared wrt to zero = .6063 Rho-squared wrt to constants = .3198		

- *The transfer penalty is worth several minutes of equivalent in-vehicle time.* The marginal rate of substitution associated with the transfer dummy varies in different specifications, but is generally equivalent to 12.0 to 15.0 minutes of in-vehicle time. (See Table 5-1.)

- *This penalty exists over and above the disutility associated with transfer waiting time.* In the same specifications that the transfer dummy is somewhat significant, transfer waiting time is highly significant. (See Table 5-1.)

- *The transfer penalty disappears when in-vehicle time is specified generically.* Our "best" general specification, that contained in Table 5-1, contains utilities in which in-vehicle time is specified as a mode-specific variable. When it is changed to a generic specification, the transfer dummy loses all significance. Such a generic specification is, however, without merit because we observed that the coefficient on transit in-vehicle time was significantly different from those on the two auto modes.

5.1.2 Number of Transfers

- *The number of transfers encountered is only important in some specifications.* When a variable is specified that indicates the number of transfers in a transit path, that variable is significant in some specifications at the .90 or so level. However, it does not maintain this level of significance in many specifications, and when substituted for the transfer dummy variable in the specification shown in Table 5-1, it is not statistically significantly different from that variable. (See Table 5-2.) In general, this variable behaves less well than the transfer dummy, implying that whether or not one has to transfer is more important than the number of times one must transfer.

Table 5-2 -- Specification with Number of Transfers

Variable	Coefficients		
	Transit	**Drive Alone**	**Shared-Ride**
Number of transfers	-.315[a]	-	-
In-vehicle time	-.043	-.120	-.118
Walk time to transit	-.035	-	-
Initial wait time for transit	-.056	-	-
Transfer wait time for transit	-.099	-	-
Auto access time to transit	-.142	-	-
Out-of-vehicle time	-	-.297	-.183
Park. & operating cost/income	-1.706	-1.706	-1.706
Transit cash fare/income	-.882[b]	-	-
(plus other household variables)			
[a] Significance below .85 level [b] Significant at .85 level All others significant at .95 level	Rho-squared wrt to zero = .6060 Rho-squared wrt to constants = .3193		

- *Transfer penalties for one versus two-plus transfers are not different.* Two dummies, one representing a single transfer and the other, two-or-more transfers, were included in a single specification to test whether the number of transfers could be better represented as some kind of step function. However, the coefficients on the two variables were not statistically different from one another, once again indicating that the important issue is really whether or not any transfer is required.

5.1.3 Transfer Waiting Time

- *Transfer waiting time is more onerous than initial waiting time.* When transit wait time was divided into the initial wait time for a transit trip, and then all subsequent (transfer) waits, the two variables were found to have significantly different coefficients. The ratio of the transfer wait to the initial is in the vicinity of 1.5 to 1.8 . (See Table 5-1.)

- *Transfer waiting time is over two times more onerous than in-vehicle time.* As mentioned above, time spent waiting to transfer is a highly significant variable. The marginal rate of substitution of transfer waiting time relative to in-vehicle time is in the vicinity of 2.0 to 3.0, depending on the particular specification. (See Table 5-1.)

5.1.4 Transfer Penalty as Represented in Cost

- *No definitive transfer penalty was found for transfer cost.* When transit trip cost was separated into initial cost and transfer cost, under the hypothesis that a "penalty" might result from the cost rather than the time to transfer, nothing conclusive emerged. The coefficients in question were not different from one another. We speculate that this finding is due, at least in part, to the wide variation in transfer fares charged in Boston, from free to full fare on the transferred-to service. Perhaps more importantly, the role of discounted transfer costs in transfer behavior could not be determined. (See Section 6.7 below.)

5.2 Other Findings

Findings presented below relate to issues not specifically related to transferring. Rather, they emerged during the course of our working with the data and estimating models; they derive from our attempts to produce a highly accurate data set in order to achieve error-free findings about transfers. These findings were already discussed in the sections on approach and data, and much more detail is provided in those sections. They are reiterated and expanded upon here for completeness.

5.2.1 Hand-Coded Versus Network Model-generated Paths/Impedances

- *The two different methods, do, indeed, lead to different estimation results.* The paths, impedances, and estimated model parameters are very different, depending on the method used, and those from the hand-coded method are superior. Table 5-3 repeats the model estimation results from Table 5-1, and compares them to results obtained using network model-generated paths and time impedances. The latter resulted in a somewhat poorer data fit, and more importantly, in the transfer dummy, transfer wait time and other travel time variables losing considerable significance. It is also interesting to note the ways in which the two models differ in terms of the relationships among their coefficients. For example, in the model that uses network-generated data, the relationship between walk and transit in-vehicle time is about 2.5, consistent with conventional wisdom. However, the ratio between these two variables in the model that uses hand-coded times is only 1.27. Furthermore, in the model that uses network-generated data, initial wait time is shown to be more onerous than transfer wait time.

Table 5-3 - Hand-coded Versus Network Model-generated Transit Time Impedances

Variable	Coefficients					
	Hand-coded			Network-generated		
	Transit	Drive Alone	Shared-Ride	Transit	Drive Alone	Shared-Ride
Transfer Dummy	-.545[b]	-	-	-.105[a]	-	-
In-vehicle time	-.042	-.118	-.117	-.032	-.046	-.053
Walk time to transit	-.033	-	-	-.013[a]	-	-
Initial wait time for transit	-.055	-	-	-.069	-	-
Transfer wait time for transit	-.100	-	-	-.031[a]	-	-
Auto access time to transit	-.139	-	-	-.031[a]	-	-
Out-of-vehicle time	-	-.309	-.193	-	-.306	-.193
Park. & operating cost/income	-1.729	-1.729	-1.729	-1.846	-1.846	-1.846
Transit cash fare/income	-.828[b]	-	-	-.923	-	-
Workers/household	-.660	-	-	-.484	-	-
Vehicles/worker <= 0.5	2.133	-	-	1.805	-	-
Vehicles/worker >= 1.0	-	1.093	-	-	1.073	-
Pop. density, production zone	.027	-	-	.025	-	-
Constant	-	1.964	.634[a]	-	2.078	.657[a]
[a] Significance below .85 level [b] Significant at .85 level All others significant at .95 level	Rho-squared wrt to zero Rho-squared wrt to const		.6063 .3198	Rho-squared wrt to zero Rho-squared wrt to const		.5679 .2591

5.2.2 Access Coding and Choice Set

Different definitions of transit availability lead to different parameter estimates. Our initial research indicated that whether or not transit was available as a choice could greatly influence final model parameters. Based on a series of tests on what constituted a reasonable walk length and drive access length, we found that the most liberal interpretation of transit availability led to the most sensible parameter estimates. These tests, along with some having to do with wait time, led to maximum individual walk lengths of 40 minutes (two miles), and unlimited drive access and wait times, (subject to the constraint that OVTT/IVTT must be less than 10). The essential finding here is that the choice set must include "poor" alternatives to get proper estimates of the true coefficients.

6.0 OUTSTANDING ISSUES

Even though this project did yield some useful and fairly conclusive information, several outstanding issues also remain. Many of these were mentioned in previous sections, but they are reiterated here because they are important issues at both a technical and policy level, and it is hoped that the work of other investigators has yielded or will yield information about these issues.

6.1 Market Segmentation and Different Types of Transfers

There are no detectable differences among transfer penalties associated with different market segments in our data set. We stratified our data set by age, income, and gender. The transfer penalty associated with these various market segments showed no definitive pattern. The variable was often insignificant in a particular stratum, owing perhaps in part to data sparseness. Moreover, where the transfer penalty was significant, it was usually not statistically significantly different from its value in other strata.

There are also no detectable differences among transfer penalties associated with different types of transfers. We tested for differences between sheltered and unsheltered transfer locations, transfers requiring use of staircases versus those on one level, and transfers between different submode pairs (bus-to-bus versus bus-to-rail, for example). As with market segmentation, no consistent patterns emerged, the data did not always support meaningful results in certain strata and penalty differences among strata were not significant.

Our inability to detect meaningful information about transfer penalties in these subcategories was a major disappointment. We believe that there probably are differences among some of these subcategories, but that our data simply did not allow us to isolate them.

6.2 Estimating Income

Related, in part, to the previous issue of market segmentation is that of household income representation. As discussed in the data section, we were obliged by the data to represent a traveler's household income as the mid-point of a quartile, and the traveler's true income could be as much as $10,000 different from our crude estimate. Since income does play an important role in household travel decisions, it would have been highly desirable to have had better data on this variable. And relying on household income as a determinant of individual behavior is another suspect, but necessary, simplification.

6.3 Hand Coding Auto Paths

While considerable effort was expended on the accurate representation of transit paths, no such parallel effort was expended on automobile paths. There are many possible auto paths, but the survey did not provide us with any data to isolate these paths. Since we could, at best, have hand-coded better minimum paths than the regional model provided, we did not feel the expected change in transfer penalty results would justify the effort required. Our experience with hand-coding transit impedances showed this process to have a major impact on transit coefficients, and we would expect major changes with improved auto impedances as well, but not on the transfer penalty. In the broader scheme of urban travel modeling, though, highway path choice decision-making is, of course, an important phenomenon that has to be modeled accurately.

6.4 Accurate Waiting Time to Replace One-Half the Headway

We used the common convention of assuming that waiting time was equal to one-half the headway up to some maximum value. Originally, in keeping with the general philosophy of using highly accurate data, we had hoped to replace this convention with a more accurate one. Average waiting time experienced by travelers, up to the point where they time their arrivals at transit stops, is related to the degree to which transit vehicles arrive at equal intervals. The greater the variance in those intervals, the greater the time spent waiting by the average randomly-arriving traveler.

We had hoped to use MBTA data on vehicle arrival times to compute more accurate waiting times, but the budget simply would not allow for this. The Peer Panel and we consider this to be highly unfortunate. Although our use of one-half the headway was not seen to undermine our findings, it remains as the one important component of transit trip time impedance that we were unable to accurately measure.

6.5 Path Choice

It would have been desirable to have information about multiple transit paths for each traveler, in order to account for path and mode choice simultaneously. The budget would not, however, allow us to hand code more than one transit path per traveler. It is not clear to us what we might have found had we done so. Experiments with maximum allowable walk distance provided some comfort that we had not confounded our transfer-related results. That is, successive runs of the transit network and pathbuilder (with a transfer penalty coded in) with ever greater maximum allowable walk distance yielded essentially the same paths. In other words, drive paths were not being substituted for walk paths in order to avoid, among other things, a transfer penalty. Even still, it would have been desirable to have accounted for path and mode choice at the same time in this research.

6.6 One-Way Versus Round Trips

A great deal of interest was generated at our Peer Panel meeting on the question of how transfer penalties might differ according to the service frequency of the transit line being transferred to. Accordingly, we agreed to separate the travel records in our data file into two groups, and to re-estimate our base specification on each group. It was decided that the easiest way to do this would be to separate travelers making production-to-attraction trips from those making attraction-to-production trips. The thought here was that transfers in the former group would tend to be from less frequent (feeder bus) to more frequent (rapid transit) services, and that those in the latter group would, by definition, exhibit the opposite characteristics.

For the model in the production-to-attraction direction, the coefficient on the transfer dummy variable is counter-intuitively positive (0.7269), but also relatively insignificant (t-statistic of 0.7). The coefficient on transfer wait time in this direction is also much greater than it is in the opposite direction, or in our "best" model. In contrast, the transfer dummy coefficient in the attraction-to-production direction is significant (t=-1.6) and is of much greater magnitude (-1.6550) than in any of the other models.

We are not fully convinced of what we have demonstrated here. The directional differences in the transfer dummy variable may largely be the residual effect of other things that are going on because the average incidence of transferring -- in total and by transit choosers relative to auto choosers -- varies only marginally by direction: it is only slightly greater in the attraction-to-production direction for auto choosers. The total average transfer wait time is 44 percent greater in the attraction-to-production direction (more high frequency rail-to-lower frequency bus transferring), so that variable's coefficient is smaller to compensate. The average total walking time is also greater in that direction, but only slightly so. More important, the average difference between transit and auto choosers is less in that direction than in the opposite direction; hence, the variable is less powerful a mode choice determinant and its coefficient is correspondingly smaller. The result of transfer wait time and total walking time having much smaller coefficients in the attraction-to-production direction is that the transfer dummy coefficient is greater and takes on more significance in that direction.

We do not think we conclusively demonstrated that the frequency of the service transferred to has an impact on the transfer penalty over and above the time spent making the transfer, nor could we decide what this says about the larger issue of how travelers make their decisions. While the penalty was apparent in the attraction-to-production direction, and not in the opposite direction, we may have been modeling an artificial distinction. Most travelers probably consider their round trip impedances in making mode choice decisions. Perhaps many do so primarily on the basis of the worst of the two one-way trips. We do not know because we did not test this. As the profession starts to model trip tours in place of trips, perhaps this issue will be resolved. But we did conclude that one should not estimate mode choice models on one-way trips unless each trip is accompanied by the traveler's reverse trip, or each is made to be representative of the round trip's average impedances.

6.7 Cost to Transfer as a Penalty

As described in the section on data, we were forced to make some approximations in characterizing fares. For the sake of consistency, we specified cash fares for transit and non-transit choosers alike. In consequence, we overestimated the cost of transferring for monthly pass holders who enjoy a certain discount. We were concerned about the potential impact of this decision on the transfer penalty, so we estimated a test model in which fares were characterized as the per-trip equivalent of monthly passes. We saw that, in fact, our original characterization was reasonable and non-biasing. The transfer penalty was unaffected by the fare characterization. In fact, using cash fares yielded a reasonable price elasticity of demand of -0.26, while using the per-trip equivalent of passes yielded an unreasonable elasticity of -0.10.

Although we concluded that fare characterization has no impact on the transfer penalty, we still do not know whether there is an additional penalty associated with the cost to transfer. The existence and frequent (but not universal)use of discount fares makes it impossible to estimate the true cost of transferring in Boston. Areas where discounted transfers are not available (or used by all) could perhaps do further research on this issue.

6.8 Parking Costs

Parking costs in downtown Boston and a few other urban centers in the region are quite high, and are a major mode choice determinant. Unfortunately, as discussed previously, parking cost is another variable for which we had incomplete data. We used reported parking cost for those who parked, and zonal averages for those who did not . We do not know whether a better measurement of parking cost would result in a different transfer penalty.

7.0 SUMMARY DISCUSSION

There is indeed a quantifiable transfer "penalty" associated with work trips in the Boston region. It would have been desirable to code multiple transit paths for each traveler in order to also examine the issue of a transfer penalty at the path choice level. It would also have been desirable to have a larger data set so that conclusive findings about transfer penalties in different market segments and for different types of transfers could have been made. However, the fact remains that we now have some useful information about such penalties at the mode choice level which can be integrated into applied modeling methods. In the future, when we forecast demand for transit services, we will be able to better account for the ridership-dampening effects of having to transfer.

Other information that came to light during this project may be as important as that related to transferring. The key feature of our approach was to develop and work with accurately measured trip impedances and other variables to the extent possible, and to search for the best possible ways to characterize variables in the model specifications. This thoughtfulness paid off because it allows us to be confident about the accuracy of our results.

At the same time, what we went through, and what we found, makes us wonder about some of the other mode choice models in use in this country. We found that highly accurate measurements of trip impedances affect estimated parameters, and that a generically specified in-vehicle time hides the transfer penalty. Although already obvious to the modeling community, we also found first-hand that how access coding is handled can have an important impact on estimated parameters. This is not new information, but taken together with our other findings, it does suggest to us that a little bit of thoughtfulness can go a long way towards creating sound, credible mode choice models.

One of the challenges we have now is in applying what we learned. Models estimated using our current, best path-building and impedance conventions will not show a transfer penalty. It is our belief, and that of at least some Peer Review Panel members, that the differences between hand-coding and network coefficients result from errors inherent in zonal aggregation, impedance averaging, and path building algorithms. In order to capitalize on what we have learned, we are now working to determine how a combination of GIS, modified network models and hand-coding can be used to simulate the hand-coding process alone, because that process is extremely time-consuming and expensive.

We cannot say to what extent findings about transfer penalties in the Boston region are transferable to other cities. There is a good chance that, in cities with mature transit systems, congested roadways and high downtown parking costs, a transfer penalty similar to that found in Boston exists. In cities where transit does not have as much of a competitive advantage, transfer penalties might be even higher. Others might want to look into this issue, as time and resources permit, because it may be that ridership forecasts done without consideration of transfer effects are inappropriately optimistic. Those who have already looked and failed to find a transfer penalty may wish to look again using some of the data development and model specification conventions employed in this project.

8.0 RECOMMENDATIONS

1. A Study is Needed That Explores the Effect of a Transfer Penalty in Application

In the estimation of our model we were able to demonstrate that a transfer penalty exists in mode choice decisions. We did not, on the other hand, explore how a transfer penalty would effect the same model in application. It would be very useful to see how model results would differ with and without a transfer penalty. This difference can be seen in applying two mode choice models that differ only in the fact that one has a transfer penalty and the other does not. The results would help quantify the effect of leaving out a transfer penalty in model application. FTA should consider funding additional research into this area. The Boston area survey and regional model are available for this purpose - this question was not answered in this present study due to resource constraints.

2. MPOs Should Be Encouraged to Look For and Utilize Transfer Penalties in Local Applications.

Our results indicate that transfers are moderately important in Boston, but they say nothing about whether transfer penalties exist elsewhere. Nevertheless, we feel that we would be remiss in our modeling and alternatives analyses if we ignored them. Doing so could potentially cause us to produce the wrong forecast ridership differences between two alternatives, one of which involves a great deal of transferring, because of biased parameter values in our mode choice models.

Given our findings, FTA should strongly encourage other MPOs to look for and utilize transfer penalties. Certainly, before any MPO embarks on implementing a model without a transfer penalty, they should do an extensive search of recent publications on mode choice issues.
For MPOs estimating new models, they should try to determine whether transferring is an important variable in local mode choice (Recommendations 3 and 4 below contain guidance for these investigations). If they are not estimating new models, but are planning to use their models in an MIS involving at least one alternative that entails lots of transferring, they should be encouraged to find other ways of guarding against the possible understatement of transfer

impacts on ridership. For instance, they might conduct some sensitivity analysis, using a range of coefficients cited in this report and other studies. Or, several minutes could be added to travel times (our study would indicate 12-15 minutes of IVTT) for a high-transfer alternative. If these tests cause the ridership to decrease to the point that an alternative no longer exhibits a satisfactory cost effectiveness relative to the no-build alternative, then that information should be dealt with in the analysis. If doing this sensitivity analysis has no great impact on the alternative's cost effectiveness, then the matter can be dropped from consideration.

3. FTA Should Encourage and Fund MPOs to Estimate Mode Choice Models and Adopt New Practices as an Alternative to Using Transferred Parameters.

Although several questions were left outstanding in this project and the exact significance of some of our findings is debatable, one thing is very clear. Relying on conventional wisdom, as manifested in contemporary model parameters that have been transferred around the country, may lead to poor mode choice models, hence poor modeling results. Our findings suggest that thoughtful consideration given to network development, data measurement, and model specification as part of a local model estimation project can lead to different and better models than those that might be transferred from somewhere else. FTA should encourage local model estimation as a way of improving on the model specifications and parameter values that have propagated around the country.

Specifically, a number of practices could be adopted now which would improve new model estimation.

A. Surveys need to be developed to elicit information useful for mode choice model estimation.

One of the drawbacks of our research was that the household survey that formed the basis of our model estimations was not developed with mode choice modeling in mind. Rather, as is typical of such surveys, ours was developed with primary consideration given to trip generation estimation needs. As such, it did not capture as many transit and carpool choosers as would have been desirable, and it did not elicit detailed enough information about the characteristics of chosen and alternative transit and carpool trips. One possible way of overcoming this drawback in other regions is for FTA to encourage MPOs to develop household travel surveys that elicit good information on the characteristics of transit and carpool trips, and to capture more users of these modes in their survey. Alternatively, FTA might encourage MPOs to supplement household travel surveys with choice-based surveys whose results can be combined with those of the household surveys.

B. Inputs and parameters should be as dissaggregate as possible, and definitions of alternatives available should be broad.

In the course of developing our estimation file, our research found a number of other common mode-choice modeling estimation practices which need to be changed. For this reason, regardless of whether or not a transfer penalty is appropriate, we recommend that zones and networks be as disaggregate as possible, that mode-specific rather than generic variables be used whenever data is available, that caps on walk and wait times be avoided or made very large, and that the definition of transit as an available alternative be broadly interpreted.

These recommendations apply to model estimation only. Given the current state of modeling practice, these recommendations may not be appropriate for model application.

4. FTA Should Fund Additional Research Into Some of the Outstanding Issues Remaining from This Project.

While we found a transfer penalty, there are many unanswered questions from our research efforts. All of these are important from the perspective of good travel model practice, and some have important, practical policy implications as well. We have two, alternative recommendations on how to proceed. In the first, a new, comprehensive research study should be funded to investigate transfer penalty and mode choice issues in general, using a survey designed for this purpose, with a larger sample size, and including a number of different cities. Alternately, a number of smaller studies should be funded, attacking different issues in different locations. The first alternative has the advantage of being comprehensive and consistent, while the second allows for different approaches and maximum flexibility. Any studies funded should adopt the practices which we discuss in Recommendation 3.

For either approach, we recommend the following issues for further investigation:

A. Methods which allow fine-grained modeling need to be developed.

Our research adds to the existing body of knowledge regarding the desirability of modeling at as high a degree of resolution as possible. Small zones or no zones, along with a correspondingly disaggregate network will yield better modeling results due to the improvement in ones ability to measure and represent transit impedances, particularly walk impedances. Implementing such disaggregation has been a problem in the past - GIS is one approach to this problem that seems promising. Path choice models which produce more realistic alternatives are also necessary. FTA should, as it has been doing, continue to fund research and encourage practitioners to move toward ever-finer-grained travel modeling.

B. Research on transfer penalties in non-work trips is necessary.

All of our research dealt with work trips. Since most of the new transit services under consideration in MISs would also serve large numbers of non-work trips, and indeed must do so in order to be considered successful, the role that transferring plays in non-work trips could well determine the success of any transit alternative. We found no research on this topic, but it seems unlikely that simply transferring work results to non-work trips is appropriate.

C. Improved methods for estimating other variables and choices should also be investigated.

In the same fashion that failure to correctly account for the influence of transferring might bias an alternatives analysis, so too can the failure to properly measure and model variables such as transit waiting time, household income, and parking cost. We developed some evidence that the way in which one measures and represents these variables has a real impact on estimated models, and may also impact ridership differences among alternatives in an alternatives analysis. There are also outstanding issues regarding the impact of transferring on transit path selection and auto mode path selection.

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